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From T. J. J. See
Berlin.

ORIGIN OF

BINARY STARS,

AN ORIGINAL THESIS,

WRITTEN FOR THE

MISSOURI UNIVERSITY

P.3072

ASTRONOMICAL MEDAL,

BY

U.S. Missouri

T. J. J. SEE,

CANDIDATE FOR THE

DEGREES, A. B., L. B., S. B.

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TO THE FACULTY

OF THE

UNIVERSITY OF THE STATE OF MISSOURI,

This Thesis is respectfully dedicated, with deep sentiments of gratitude for whatever of merit it may, thro' the beneficent influence of their culture, possess.

Salutation and Respect,

THE AUTHOR.

ORIGINAL THESIS.

SUBJECT: ORIGIN OF BINARY STARS.

PROPOSITION: THE BINARY STARS HAVE COME INTO EXISTENCE BY A PROCESS OF COSMIC EVOLUTION; AND THEIR SYSTEMS HAVE BEEN BROUGHT TO THEIR PRESENT CONFIGURATIONS BY A PROCESS OF TIDAL EVOLUTION ANALOGOUS TO THAT TRACED OUT BY PROF. G. H. DARWIN IN HIS THEORY OF THE LUNAR-TERRESTRIAL SYSTEM.

In order clearly to understand the Darwinian conception, let us begin this thesis by an introduction on the historical developement of the theory of tides and its expansion into the general theory of cosmic tides, recently employed by Prof. G. H. Darwin in his researches on the origin of the Moon. Sir Isaac Newton, in the latter part of the Seventeenth Century, formulated and propounded his theory of universal gravitation. By this theory he was enabled to give a rational explanation of the ebbs and flows of the sea. He declared that terrestrial tides arise from the mutual attraction of the different heavenly bodies and the Earth, especially the Moon and the Sun. And he showed by mathematical calculation that his theory "abundantly served to explain all the motions of the heavenly bodies and of

our sea." Newton thus began to investigate the tides and to deduce a general theory; and he left it to his successors to build up and polish, by the finer touch of mathematical analysis, that vast and glittering edifice that now rises over foundations unshaken and immovable, laid in the tidal phenomena of the Solar System, phenomena now clear and transparent, but then dim in darkness and still earlier wrapt about by the mantle of impenetrable night; an edifice which towering aloft now aspires even unto the whirling stars of the Milky Way.

After Newton the theory of tides was not materially advanced until the latter part of the Eighteenth Century, when Laplace published his profound investigations in the Mécanique Céleste. This illustrious mathematician, taking up the work where it had been dropped a century before by his great predecessor, by the application of mathematical analysis, developed by himself and especially by Lagrange, went beyond both Newton and his countrymen, who had adhered to Geometrical methods. With the growth of knowledge pertaining to the earth's surface, and the depth and configuration of the body of fluid that covers this planet, the theory of terrestrial tides has been gradually improved. Not only has this theory been developed and perfected, but the general tidal theory has been extended to all bodies that exist in the immensity of space. And since the fluids that cover the heavenly bodies are all viscous, the resultant lagging of cosmic tides produces a secular change in the mean distance of the bodies as well as in the elements of the orbit, as will be presently shown. Even in case of bodies devoid of fluid we still have cosmic tides, since no cosmic body is absolutely rigid when subjected to the distorting power of cosmic forces. Hence this subject has come to be one of vast philosophic importance of recent

years. This extension of the tidal theory has enabled mathematicians by reasoning forward to predict the ultimate tendency of a cosmic system; and conversely, by reasoning backward, they should likewise be able to tell something of the former history and even of the origin of such a system. Helmholtz says in this connection: "Physico-Mechanical laws are, as it were, the telescopes of our spiritual eyes by which we pierce the darkest night of time past and to come."

The future of the planetary system under the influences of tidal friction, indeed, has been made evident for some years; but it is only in about the last decade that the solution of the converse problem—namely, to trace the tidal history of this system—has been attempted. In case of the Lunar-Terrestrial system this problem has been solved in a masterly and satisfactory manner by Prof. G. H. Darwin. He traces the moon back spirally towards the earth, and finds that when the two spheroids are in close contiguity, the time of revolution of the lunar spheroid was almost exactly coincident with the time of the earth's rotation. The time of revolution of the moon must have been, by Kepler's law, more than two, and less than two and a half, hours; while the time of terrestrial rotation, consistent with equilibrium, supposing the earth to have been a fluid mass, perhaps yet plastic and glowing, of its known density, could not have been over two hours and twenty minutes. This was just at the beginning of the Lunar-Terrestrial System, when tidal friction had not yet begun to grind down axial velocity and expand orbital range. If we suppose the Lunar-Terrestrial mass to be in the state of most rapid rotation consistent with equilibrium, it is at once plain that the slightest increase in the axial velocity of the fluid mass, above two hours and twenty minutes would bring about disruption, and a satellite or satellites would be formed. The

detached portion might be in one mass, but the latest investigation seems to indicate that it would in general be a flock of meteorites, which, however, would finally be brought together into one mass by the mutual attraction of the bodies revolving in almost the same orbit. Such is the Darwinian conception of the genesis of the Moon. The Solar tide is thought to have been instrumental in starting the disruption made possible by the contraction of the rapidly-revolving and glowing plastic mass. Mr. Darwin, proceeding on this hypothesis, explains the origin and present configuration of the Lunar-Terrestrial System. He attempted to investigate the origin of the planetary system on the same principle, but found that it could probably not be satisfactorily applied in any other part of our system.

The writer now proposes to extend this Darwinian conception to the Binary stars, and to inquire if the hypothesis will suffice to explain the genesis of those vast systems of suns that float away in the depths of the firmament. In investigating this subject we must, according to the spirit of scientific inquiry, deduce the past history of nature from the principles that are operative in making the present history. This general principle of the continuity of nature presumed, we proceed to a consideration of tidal influence in circular orbits.

LEMMA I.

If two viscous spheroids, a Primary and a Secondary, be revolving in circles about their common center of mass, the resulting tidal friction increases the time of rotation of the Primary and expands spirally the orbital range of the Secondary.

Let Fig. 1. represent two viscous spheroids deformed by tidal action. Let the plane of the paper

be the plane of the orbital motion. Let the rotation be as indicated by the arrow in the figure.

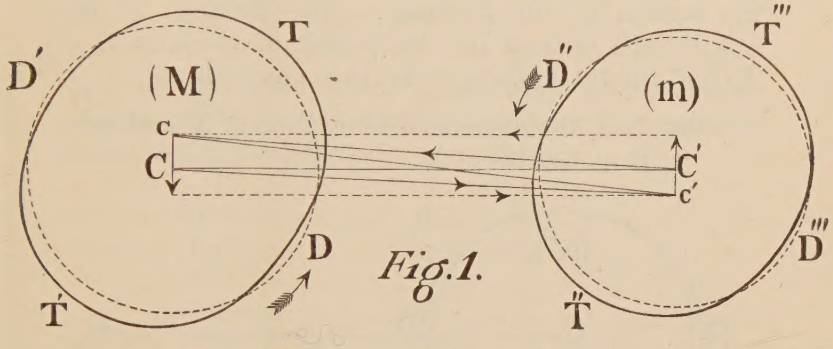

Fig. 1.

The time of rotation of the Primary is supposed to be less than the time of revolution of the Secondary. Let us suppose further that the spheroids are fluid throughout, or have solid nuclei covered with films of fluid that yield to cosmic tidal forces.

If the fluids were frictionless there would be a tide on both bodies directly between their centers of mass on the line C C′, and of course also on the opposite side of each body. But if the fluid be frictional or viscous, as all known fluids are, the major axis of each tidal spheroid will point in advance of the other spheroid. In other words the figure will represent the configuration of these two bodies. Let us now consider the influences of tidal friction under such conditions. Let us suppose for the present that the Secondary (whose attraction as felt upon the Primary is centered at C′) is a weighted point of mass m. Let us henceforth also denote the mass of the Primary by M. The tide T is nearer m than T′; hence T is greater than T′. So also the depression D′ is farther away from m than D, and hence less than D. The resultant of the action of M on m must therefore be in some such direction as C′ c.

The action of m on M is equal and counter. The resultant C'c not passing through the center of the Primary, must produce a couple tending to retard the motion of the Primary. The moment of the couple will depend on the length of the arm C c. To find the tidal effect let us reason as follows:

Put D = Distance between centers of M and m.
" R = Radius of M.

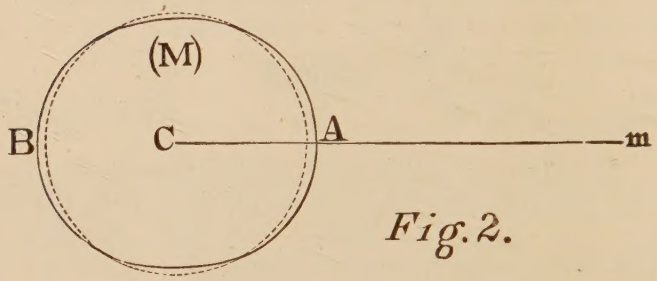

Fig. 2.

$$\text{Attraction at A} = \frac{m}{(D-R)^2} \quad \ldots\ldots\ldots\ldots (1)$$

$$\text{Attraction at C} = \frac{m}{D^2} \quad \ldots\ldots\ldots\ldots (2)$$

$$\text{Attraction at B} = \frac{m}{(D+R)^2} \quad \ldots\ldots\ldots\ldots (3)$$

Subtracting (2) from (1) and (3) from (2) we have:

$$\frac{2\,m\,D\,R - m\,R^2}{D^2\,(D-R)^2}$$

= excess of attraction at A over C . . . . . (4)

$$\frac{2\,m\,D\,R + m\,R^2}{D^2\,(D+R)^2}$$

= excess of attraction at C over B . . . . . (5)

Omitting the second term of the numerators which is

very small as compared with the first, and omitting R from the denominators, (4) and (5) become

$$\frac{2\,m\,R}{D^3} \text{ and } \frac{2\,m\,R}{D^3}$$

very nearly; but (5) is easily seen to be always slightly less than (4) while D is finite. For, separate the expressions as follows:

$$\frac{2\,D-R}{(D-R)^2} = \frac{D}{(D-R)^2} + \frac{1}{D-R},$$

$$\frac{2\,D+R}{(D+R)^2} = \frac{D}{(D+R)^2} + \frac{1}{D+R};$$

whence clearly

$$\frac{2\,D-R}{(D-R)^2} \diagdown\!\diagup \frac{2\,D+R}{(D+R)^2}.$$

The efficiency of the tide-generating force therefore varies directly as m and as the Radius of the Primary, and inversely as the cube of the distance of m. But the moment of the tidal couple varies as the square of the tide-generating force which itself varies inversely as the cube of the distance. Hence moment of tidal couple varies inversely as the sixth power of the distance. The tidal friction caused by attraction of m has already been seen to retard the rotation of M.

Let us now consider the effect of M's tidal friction on the orbital motion of m. If the force acting on M be resolved along and perpendicular to C C′, the perpendicular component being exerted tangentially to the orbit of m (when it is a circle only, but we shall presently treat the ellipse, the actual figure of nature) tends to accelerate its velocity. By the

action of this component the body m would be carried further from C than it would be drawn back by the attraction of M, and m would describe a spiral the coils of which would be very nearly circular and almost coincident. If now we furthermore resolve tangentially and perpendicular to the spiral the force C′ C, the tangential component tends to retard the velocity of m, whilst the component perpendicular to the spiral tends to make the spiral more nearly a circle.

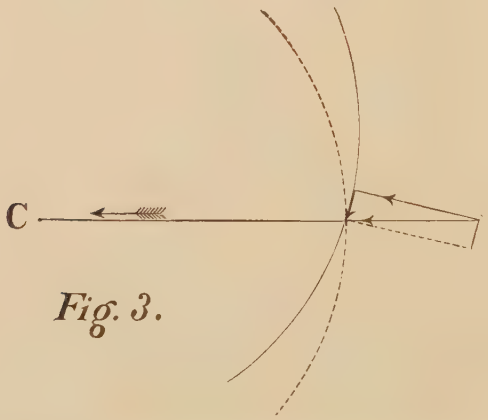

Fig. 3.

But the disturbing component previously treated tends to accelerate the velocity of m; and in nature this accelerating force is in the ascendancy. The moment of momentum of the whole system remains unchanged, and the moment of momentum of the Primary diminishes, so that the orbital moment of momentum must increase. But orbital moment of momentum increases only with increase of distance and decrease of linear and angular velocity of m, as is evident from the Darwinian equation:

$$u = M\left\{\frac{m\,D}{M+m}\right\}^2\omega + M\left\{\frac{M\,D}{M+m}\right\}^2\omega = \frac{M\,m}{M+m}D^2\omega\,. \quad (6)$$

Tidal friction therefore diminishes rotation of M, increases distance of m, and decreases its orbital and angular velocity. The component due to tidal friction thus gradually leads the Secondary away on a spiral, and at the same time retards the rotation of the Primary.

In our reasoning we have regarded m as merely a weighted point, not itself subject to tidal deformation. Now if we consider M in the same way a weighted point, the center so far as m is concerned being at C, we can apply similar reasoning to the Secondary m. And results exactly similar will be deduced. Hence in this event, which in nature always actually takes place (since no cosmic body is rigid, but subject, in some degree at least, to tidal deformation), we have two components conspiring together to increase the distance between the spheroids, and decrease angular and orbital velocities; and plainly also components tending to lengthen the time of rotation of both Primary and Secondary.

Cor. 1. These forces would clearly continue to act until synchronism was attained between time of axial rotation and orbital revolution. When this state is attained, the bodies will, if left undisturbed by outside forces, then revolve about their common center of mass without further change forever. In nature such an event could perhaps never occur; a disturbing force would turn the tidal protuberances the other way, and then the bodies would gradually approach each other on a spiral concentric and almost coincident until collision would be the final result.

THEOREM I.

The disturbing components of frictional tides raised by the mutual attraction of two viscous spheroids revolving in ellipses about their common

center of mass tend to produce a secular increase in the excentricities of the orbits; and this increase of the excentricity tends to augment the rate of the increase of the excentricity.

In our consideration of this theorem let us take the Secondary spheroid as a mere point; and let the time of rotation of the Primary be less than the time of revolution of the Secondary. Other conditions being similar to those in our previous consideration of the effect of tidal influence, we proceed to consider the effects of the difference of distance in elliptic orbits. This theorem may be very easily grasped when presented as follows: The tendency of frictional tides is to enlarge the orbit by pushing it out at the different points. By virtue of the momentum of a cosmic body this push will give to the orb an harmonic swing that will enlarge the path of the body most not at the point at which it is exerted, but at the opposite point. Thus the influences exerted at Perihelion will change the orbit most at Aphelion, and conversely. Now this pushing force varies inversely as the cube of the distance. Hence the tendency will be to increase the Aphelion distance inversely as the cube of the Perihelion distance; and to increase the Perihelion distance inversely as the cube of the Aphelion distance. But this will necessarily change the excentricity of the orbit, as the following analysis will readily show:

Put ∞_P = Perihelion distance.

Put ∞_A = Aphelion distance.

Then $\infty_P = a\ (1-\varepsilon)$.

And $\infty_A = a\ (1+\varepsilon)$.

whence, also, $$\frac{\mathfrak{a}_P}{\mathfrak{a}_A} = \left\{\frac{1-\varepsilon}{1+\varepsilon}\right\} = \varkappa, \text{ (say)}, \quad \ldots (1)$$

The force exerted at Perihelion and effective in enlarging the orbit at Aphelion

$$= \frac{K}{\mathfrak{a}_P^3} = \frac{K}{a^3(1-\varepsilon)^3} \quad \ldots\ldots\ldots\ldots (2)$$

The force exerted at Aphelion and effective in enlarging the orbit at Perihelion in like manner

$$= \frac{K}{\mathfrak{a}_A^3} = \frac{K}{a^3(1+\varepsilon)^3} \quad \ldots\ldots\ldots\ldots (3)$$

By virtue of this force the axis of the ellipse increases by small increments each revolution. Call these increments $\Delta\mathfrak{a}_P$ and $\Delta\mathfrak{a}_A$ respectively. Accordingly, we desire now to investigate and find by what law this increase is regulated in order to see if it changes the elements of the orbit. Now, these increments are proportional to the forces effective for pushing the orbit out at the respective points. Hence we have

$$\Delta\mathfrak{a}_P : \Delta\mathfrak{a}_A :: \frac{K}{a^3(1+\varepsilon)^3} : \frac{K}{a^3(1-\varepsilon)^3} \quad \ldots\ldots (4)$$

$$\text{or } \frac{\Delta\mathfrak{a}_P}{\Delta\mathfrak{a}_A} = \left\{\frac{1-\varepsilon}{1+\varepsilon}\right\}^3 = \varkappa^3 \quad \ldots\ldots\ldots (5)$$

From our former equation, (1), of the ellipse in which the excentricity remains constant we have $\frac{\Delta\mathfrak{a}_P}{\Delta\mathfrak{a}_A} = \varkappa$; in other words, this fraction $\varkappa$ is the ratio of the increments added to $\mathfrak{a}_A$ and $\mathfrak{a}_P$ in varying the ellipse so as to increase its size without changing the excentricity. But in the above case, (equation 5),

supposed to represent the actual course of nature, we have found the equation to be $\frac{\Delta \infty_P}{\Delta \infty_A} = \varkappa^3$. That is the ratio of variation of the ellipse of nature is $\varkappa^3$ times the ratio of variation in the stable ellipse. And since $\varkappa$ is always fractional, the excentricity must always increase; and not only will it increase, but the rate of increase will become ever greater and greater as the excentricity increases.

In our reasoning we have used only two points of the orbit, but manifestly the same reasoning holds for any two opposite points of the orbit; hence, for the entire ellipse. We conclude, therefore, that tidal friction tends to increase the excentricity of the orbits of all cosmic bodies; and the increase of the excentricity augments the rate of increase of the excentricity. Like reasoning applies to the tide produced on the Secondary. The two components thus fall together and both conspire to bring about the same secular effects.

Cor. 1. Reasoning exactly analogous to this will show that this increase in the excentricity and size of the orbit must go on until synchronism between time of axial rotation and orbital revolution is attained; if then a disturbing force turn the tide the other way the reverse effect will be produced. Otherwise the bodies will revolve about their common mass-center without relative rotation forever.

THEOREM II.

Tidal friction causes a slow progression of the line of the Apsides.

Let us take any point in the accompanying ellipse, except the Perihelion and Aphelion, say p; and let us resolve the disturbing component along and perpendicular to the tangent at that point. Denote this

whole component by E, and the angle between E and the tangent to the curve by φ. The component E is always perpendicular to ρ, the radius vector.

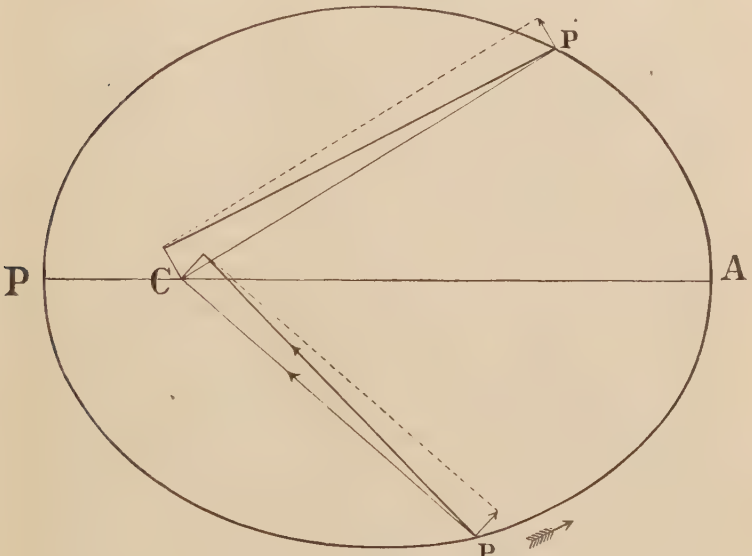

Fig. 4.

Denoting these resulting components by C with subscripts t and p respectively, we have $C_t = E. \cos \varphi$, and $C_p = E. \sin \varphi$. Clearly these components C_t tending to accelerate the motion of the body in the orbit, and C_p tending to draw the orbit in at p, will hold for the first half of the orbit starting from Perihelion. There is, therefore, on this side of the orbit, a component tending to make the line of the Apsides advance.

Let us now examine the effect of the disturbing component on the other side of the orbit. Take any point of the orbit between Aphelion and Perihelion,

say p′, and resolve the disturbing component as before, using the notation :

$$C_t = E. \cos\varphi,$$
$$C_p = E. \sin\varphi.$$

And it will be observed that C_p is in both cases like directed. Hence, the perpendicular components on both sides of the orbit tend alike to bring about a slow progression of the line of the Apsides.

Cor. 1. It is plain that the perpendicular component $C_p = E. \sin\varphi$ can not exist in the case of circular motion. For in the circle the angle $\varphi = 0$, and $\sin\varphi = 0$; also $\cos\varphi = 1$. But the circle being the special ellipse in which the excentricity is zero, and the two foci coincide at the center, it is equally plain that in an ellipse of any excentricity this component will exist ; and relative to the tangential component it will increase with an increase of the excentricity, since this will increase φ, and hence $\sin\varphi$.

Cor. 2. This line of the Apsides, being thus constantly turned by an increasing force, having been accelerated thro' many ages, will eventually move very rapidly, since it is never in any way retarded. Theoretic progression, being based upon calculations which take no account of this component, may, therefore, in some cases be greatly in error.*

* These Theorems are original with the writer; after he had discovered and proved them by analysis, as above, he received, just from the press, the XXIII volume of the *Encyclopædia Britannica*, in which a proposition of like import to Theorem I is stated by Prof. Darwin, as well as several other points which had occurred to the writer independently. He had previously met only notices of Prof. Darwin's work. The writer then, however, made a review of Prof. Darwin's masterly article, and the same is hereby acknowledged. Several other secular effects of tidal friction are deduced by Prof. Darwin, such as the decrease of the inclination of the orbit of a satellite (or in our theory of the triple stars, of the orbit of the nearer companion) and increase of obliquity of ecliptic. But perhaps only the former of these two secular effects can ever be observed from the earth owing to the enormous distances of the stars, and the impossibility of magnifying them even with the most powerful telescopes.

THE INVESTIGATION.

Let us now turn to our subject and see if the facts of observation can be coördinated under our proposition. But before proceeding it will be allowable to bring forth the Laplacean argument, which in this case is as follows: In the foregoing discussion we have deduced certain general results that ought to exist, and we now compare the theoretic system thus deduced with the actual system of nature. If, therefore, we find concordance between the theoretic system and the actual system of nature, it must be regarded as a strong argument for the validity of our reasoning and for the tenability of our hypothesis. At present over 10,000 double stars have been observed, the great majority of which will prove to be Binary. The entire orbits of about 50 Binaries have been traced; and considerable arcs of the orbits of over 200 other Binaries have been described since their discovery. Let us, then, first present the tables of observation which, altho' limited, are, nevertheless, believed to be broad enough for the foundation of a substantial argument.

SOLAR SYSTEM.

SOME ELEMENTS OF THE PLANETARY ORBITS.

Name.	Period (years)	Excentricity.	Authority.
Mercury	0.21	0.205	Leverrier.
Venus	0.61	0.006	Leverrier.
Earth	1.00	0.016	Leverrier.
Mars	1.88	0.093	Leverrier.
Jupiter	11.86	0.048	Leverrier.
Saturn	29.46	0.056	Leverrier.
Uranus	84.02	0.046	Newcomb.
Neptune	164.78	0.008	Newcomb.

BINARY-STAR SYSTEMS.

Newcomb and Holden's Table, (rearranged), giving some of the elements of the orbits of 30 of the most accurately determined Binary Stars.

Name.	Period (years)	Excentricity.	Calculator.
ζ Cancri (A and B)	62.4	0.00(?)	O. Struve.
ξ Librae	95.9	0.08(?)	Doberck.
Σ 3121	37.0	0.26	Doberck.
δ Cygni	415.1	0.28	Behrmann.
η Coronae Bor	40.2	0.29	Flammarion.
α Geminorum	1001.2	0.33	Doberck.
γ Coronae Bor	95.5	0.35	Doberck.
ζ Cancri (A and C)	60.5	0.37	Flammarion.
ξ Ursae Maj. (A and C) . .	60.6	0.37	Flammarion.
ξ Ursae Maj. (A and B) . .	60.6	0.38	Hind.
ρ Eridani	117.5	0.38	Doberck.
70 Ophiuchi	92.8	0.39	Flammarion.
ζ Herculis	34.6	0.41	Flammarion.
Σ 3062	104.4	0.46	Doberck.
42 Comae Ber	25.7	0.48	Dubiago.
λ Ophiuchi	233.9	0.49	Doberck.
ω Leonis	114.6	0.55	Doberck.
η Cassiopeae	222.4	0.57	Doberck.
Σ 1938 and μ^1 Boötis. . . .	280.3	0.60	Doberck.
τ Ophiuchi	217.9	0.61	Doberck.
36 Andromedae	349.1	0.65	Doberck.
ζ Aquarii	1578.3	0.65	Doberck.
Σ 1768	124.5	0.66	Doberck.
α Centauri	85.0	0.67	Hind.
γ Coronae Aus	55.5	0.69	Schiaperelli.
ξ Boötis	127.4	0.71	Doberck.
44 Boötis	261.1	0.71	Doberck.
γ Leonis	402.6	0.74	Doberck.
σ Coronae Bor	845.9	0.75	Doberck.
γ Virginis	175.5	0.87	Flammarion.

Average excentricity of these orbits, .49 ; or, omitting the two excentricities in doubt, .52.

PROF. YOUNG'S MORE RECENT TABLE.

Name.	Period (years)	Excentricity.	Calculator.
δ Equilae	10 to 12	(?)	Not comput'd
η Coronae Bor	41.6	0.26	Duner.
μ Herculis	54.2	0.30	Doberck.
α Geminorum	996.8	0.34	Thiele.
γ Coronae Bor	95.5	0.35	Doberck.
ζ Cancri	60.3	0.39	Seeliger.
ξ Ursae Maj	60.8	0.42	Pritchard.
ζ Herculis	34.4	0.46	Doberck.
4 Aquarii	129.8	0.46	Doberck.
70, p, Ophiuchi	94.4	0.47	Pritchard.
42 Comae	25.7	0.48	Dubiago.
α Centauri	77.4	0.53	Elkin.
ω Leonis	110.8	0.54	Doberck.
Sirius	44.0	0.59	Pritchard.
η Cassiopeae	195.2	0.62	Gruber.
36 Andromedae	349.1	0.63	Doberck.
ξ Boötis	127.3	0.70	Doberck.
γ Leonis	407.0	0.73	Doberck.
σ Coronae Bor	845.9	0.75	Doberck.
γ Virginis	185.0	0.90	Thiele.

Average of the 19 excentricities, 0.52.

Average excentricity for the 8 planetary orbits 0.044; or in other words, the Binary orbits on the average are more than ten times as excentric as the planetary orbits. Below is given a circle representing the orbit of a planet of the solar system having excentricity too small to enable the eye to distinguish it from a circle; also the mean orbit for the 28 Binaries, $\varepsilon = 0.52$; and the most excentric Binary orbit, that of γ Virginis, $\varepsilon = 0.90$.

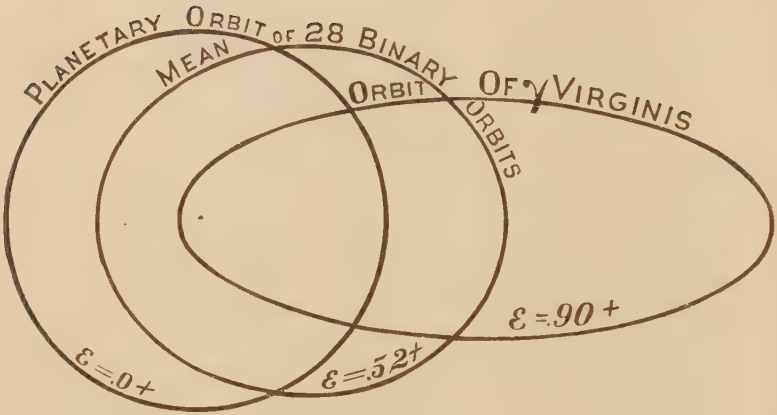

Fig. 5.

REMARKABLE EXCENTRICITIES OF THE ORBITS OF BINARY STARS.

On looking over the above table one cannot but be impressed with the remarkable excentricities which the orbits of the Binary stars present. (The arrangement of the table giving a progression is intentional.)

And since we find not only great excentricities in this table; but that all these excentricities are remarkably, tho' not uniformly great, the question arises: Can not some rational explanation be given of these astounding phenomena?

THE BINARY SYSTEMS DO NOT BELONG TO THE SAME CLASS OF SYSTEMS AS THE PLANETARY SYSTEM.

In opening this investigation let us first inquire whether the Binary stars and the planets of the solar sytem belong to the same class. Let it be assumed that they do belong to one class. Then, we may reason as follows: What is the chance that 28 Binaries should have orbits so extremely excentric

that all their excentricities should fall without the range of planetary excentricity. If the distribution is a matter of chance, we should expect that half of these excentricities would fall above, and half below, the mean value for excentricities in the planetary system. This mean value is 0.044. But not only do all excentricities of Binary orbits fall above this mean, a most remarkable fact, but even considerably above the extreme case of the solar system —the orbit of Mercury—where the excentricity is. 20. For the smallest Binary excentricity reliably determined is .26, and the mean of the 28 best orbits is .52. What a remarkable occurrence! Let us, then, reason as follows by the theory of Probabilities: The chance of the excentricity of any particular orbit falling on one side of .044 is $\frac{1}{2}$; the chance that it will fall on the other side is $\frac{1}{2}$. Hence the chance that all these excentricities should fall on the same side of the planetary mean—*i. e.* above .044—is $(\frac{1}{2})^{28}$, or less than one three hundred millionth. And infinitely smaller still is the chance that all these excentricities would fall beyond the range of the extreme planetary excentricity. The chance, therefore, of these Binary excentricities being so great, taking the excentricities of the principal orbits of the planetary system as a basis, practically vanishes. It is, therefore, practically certain that the Binaries and planets of the solar system *do not belong* to the same class. We are therefore led to the sure conclusion that the Binary stars constitute a class of bodies essentially different from that presented in the planetary system. And since the Binaries are bodies of a different class it will not be strange if we find the explanation of their excentricities in a cause which has probably not been of the first importance in the developement of planetary excentricities.

EXCENTRICITIES EXPLAINED.

We can not suppose that the errors of observation have been important in producing these great excentricities. The explanation of them must, therefore, be sought in the forces of nature that have been operative in the origin and developement of Binary-Star Systems. But we have already deduced some theorems that may be employed in this investigation. We have found that each result could have been produced by the influence of cosmic tides, supposing these bodies to have once been viscous and plastic in their nature, as we know the planets of the Solar System once certainly to have been from their visible ellipticity. But the degree of plasticity and viscosity necessary to have produced such remarkable excentricities, implies a state of fluidity, and fluidity implies heat. We are therefore led back to a time in cosmogonic history when the Binary Stars were (and perhaps they are still at least molten) viscous fluid spheroids revolving about their common center of mass.

How were these spheroids formed? If we suppose them to have been formed in any wise like the planets of the Solar System, *i. e.*, from condensation of the circular nebular rings detached from the periphery of a revolving discoid, then, we should expect to find the smaller excentricities much the most frequent. In fact, if this be their origin, there is no known explanation of these great excentricities. For, the excentricities of the planetary orbits are due mainly to the perturbative influence of the different bodies of that system. Such, however, cannot be argued with regard to the double-star systems; for there are no disturbing bodies, unless they are invisible and this will presently be made extremely improbable. On the other hand, if we suppose the Binaries to have originated according to the Darwinian conception of the origin of the

Lunar-Terrestrial System, tidal friction on the great stellar spheroids being very potent in increasing the excentricities of their orbits, these great excentricities are easily explicable. For two bodies originating according to the Darwinian conception would early assume spheroidal forms and revolve in orbits nearly circular, but the dragging of cosmic tides might eventually bring about any excentricity whatever.

SUPPOSED PROCESS OF BINARY EVOLUTION.

As the nebula condenses, the rotation becomes ever swifter and swifter until the spheroid gradually flattens out into a rapidly-revolving discoid. The contraction at this stage is almost solely from the direction of the poles; each particle falls not toward the center of the mass but toward the plane of the periphery of the revolving fiery plastic fluid mass. Finally the discoid will have attained the most rapid rotation consistent with fluid equilibrium; and the slightest acceleration of the velocity of rotation will rupture the mass, and give rise to a separation. But before this condition of unstable equilibrium is attained, unless the original nebula was absolutely symmetrical and homogeneous, the chances are almost infinite that a lump will have been formed somewhere on the periphery (for this will be the case unless the plastic spheroid is perfectly symmetrical and absolutely homogeneous—a condition not fulfilled in actual nature) by virtue of which not a particle nor particles, but a mass or masses will be detached that will circulate around the Primary. When several masses are thrown off they will finally be gathered together and agglomerated into one mass. Thus we see that the formation of a ring would be the exception, not the rule; whilst it is mathematically conceivable the chance against it is practically infinite.

TRIPLE AND MULTIPLE STARS.

A Binary having been formed, under the distorting power of resulting cosmic farces, it is quite plain how a division of one of the components might give rise to a triple star, a division of the other to a quadruple star, and so on. Thus any multiple star could be formed. The observations thus far available on the Triple and Multiple Stars are not extensive owing to their extremely slow motion. But enough observations have been made to show that the components of Triple Stars move in a common direction and nearly in a common plane. Hence we are led to infer that the Triple, and Multiple Stars also, have originated by the above mentioned process.

Resuming, then, we may look upon the systems of Binaries as having originated by the too-rapid rotation of the original viscous and plastic fluid masses. In this way a part would be separated, possibly, tho' not necessarily, in one mass, possibly in a flock of meteorites. If separated in one mass, the process of grinding down axial rotation and of expanding orbital range with increase of excentricity would go slowly on. If the separated mass should take the form of a flock of meteorites, final agglomeration of these would still leave only one mass. The process of secular change would then go on as mentioned above just as if this one body were the product of the original birth-throe. It is plain, furthermore, that in case of large bodies, like the Binary Stars are known to be, the influence of tidal friction becomes very great.

TIDAL FRICTION A CAUSE ENTIRELY ADEQUATE TO EXPLAIN THE PHENOMENA OF BINARY SYSTEMS.

This becomes evident when we recall what has been said in regard to the tidal effects of mass and distance of the components of a star and their mutual

relation of magnitude. Here we have two suns raising tides upon each other. At present they are not in general far different in diameter from our sun, say about one million miles. But when they came into existence, millions of years ago, separating at the stage of incipient fluidity, they were certainly much larger than at present, whilst their orbits do not differ much from the larger orbits of our planetary system. It is quite plain therefore that if a moon 2,000 miles in diameter, separating at the plastic stage, in a system so unequal as the earth and moon, as Prof. Darwin has shown with strong probability to have really occurred, should recede to a distance 100 times its diameter, that two vast glowing suns, comparable in mass and several million miles in diameter, separating at a much earlier stage of developement, might recede to a distance 1,000 times their present diameter. An exhaustive mathematical investigation of this subject is not practicable at present; but may be undertaken at some future time. It should be stated, however, that much of Prof. Darwin's reasoning with respect to the earth and moon would perhaps apply with the same rigor to the great Binary Suns. But making all reasonable allowance, the causes assigned are seen to be entirely sufficient to produce the observed results—*i. e.*, make the components of Binary Systems recede from each other to their present distances. We might expect, therefore, not only great excentricities in the orbits of great Binaries, but that these excentricities should be developed in a much shorter time than corresponding excentricities in the orbits of smaller bodies.

LAPLACEAN HYPOTHESIS FAILS.

Whilst the hypothesis of Laplace will account for the phenomena of the planetary system and some of the phenomena of the Binary-Star Systems, it will

not suffice to explain the uniform comparability of the masses of the components of the Binary Stars, and especially the great excentricities of their orbits. Of these two fundamental facts the hypothesis of Laplace fails to give any satisfactory explanation. It has been seen how the phenomena of excentricity admit of a clear explanation under the Darwinian Hypothesis, and we shall presently see how the case stands with respect to masses.

"NEBULAR HYPOTHESIS" LARGELY ASSUMED.

The theory herein developed is in no way contradictory to the "Nebular Hypothesis," now so well established as representing substantially the process of evolution actually represented in the origin of the Solar System. The argument for the Laplacean hypothesis in the planetary system is so overwhelming as to place it beyond all reasonable doubt. The probability of its validity amounts almost to certainty. The more general proposition that all the bodies of the visible cosmos have been developed from nebulae, and before that from a still more chaotic condition of matter, will not here be discussed. It must be remarked, however, that this proposition rests upon evidence that can hardly be disputed. Its discussion very naturally accompanies the Laplacean Hypothesis whose validity in general is here tacitly assumed. We are here concerned not with the tenability of the "Nebular Hypothesis", but whether the hypothesis as applied to the Solar System suffices to explain the origin of Binary stars.

Our hypothesis assumes:

I. That the stars have been formed by nebular condensation under the force of gravity.

II. That this condensation, as is evident, would give rise to heat and rotary motion.

III. That there would be a final balancing of centripetal and centrifugal forces which would make evolution of cosmic bodies possible either by separation of rings of vapor, or by detachment of fluid masses. The latter alternative of III. is the Darwinian conception.

HYPOTHESIS OF DARK BODIES INADEQUATE TO EXPLAIN THE REMARKABLE EXCENTRICITIES OF THE ORBITS OF THE BINARY STARS.

It might be argued that these great excentricities result from the perturbative influence of dark bodies in the same manner in which the excentricities of the orbits of the planetary systems have been produced. But this proposition is clearly without logical foundation. For if dark bodies large enough to produce the observed effects exist, they would in all probability produce such perturbations in the motion of Binary components as to be detected by observation. But most inconceivable of all is that bodies necessarily so large, relatively, and perhaps absolutely, in the same system, having a common origin, should have become so dark as to be invisible. And especially is this proposition unreasonable when we remember that all the 28 Binary orbits have the common property of great excentricity in so high a degree. It seems, therefore, eminently reasonable either that disturbing bodies, if such exist, being necessarily of great mass, and cooling, therefore, slowly, would not all be invisible, or that, if dark, their existence would have been detected by observed perturbations. This argument against the hypothesis of dark bodies is overwhelming when we remember that about one-half of the stars of the firmament are multiple, and of these multiple stars the great majority—about nine tenths—are Binaries. Binary

stars seem to be the general result of Darwinian evolution; multiple stars the exception, altho' formed perhaps by the Darwinian process.

BINARY-STAR SYSTEM CONTRASTED WITH THE PLANETARY SYSTEM.

In the Stellar Universe, as has been seen, we find one Sun revolving in a very excentric orbit about another, or more accurately about their common center of mass; these are the Binary stars, of comparable masses, and long periods. In striking contrast to this, we have, in the planetary system, eight principal planets, their systems of secondaries, asteroids, comets, meteors, etc., altogether small in mass compared to the mass of the central body, revolving around the center of mass of the whole system. This center of mass is always within or near the body of the Sun. We find also the planetary orbits to have small excentricities. So small are these excentricities that the most excentric planetary orbit (that of Mercury, .20) has less excentricity than the least excentric Binary orbit, .26. Again in the Solar System we find the masses of single planets entirely incomparable to the mass of the central body—the Sun. From α Centauri Jupiter would appear as a Star of the twenty-first magnitude and only 5″ from the Sun. The period of revolution of bodies of the Solar System is generally shorter than the revolution of Binaries, but undetermined conditions of space and mass forbid any accurate comparison. The great number of bodies of the planetary system and their small size, however, seems to invalidate the Laplacean conception as applied to the Binaries. Comets and meteors very likely belong to the Binary Stars. And not being native to the Solar System, their excentric orbits are neither an argument against Laplacean evolution, nor can they

be considered any argument favorable to the Darwinian evolution in the Binary Systems. The great process of cosmic evolution seems to be presented in two phases:

I. Laplacean, "Nebular Hypothesis," exemplified in the Solar System.

II. Darwinian, "Origin of the Moon," exemplified in evolution of Lunar-Terrestrial System, and, if we be correct, in the developement of the systems of Binary Stars.

GREAT MASS OF BINARIES.

PROF. YOUNG'S TABLE OF BINARY MASSES.

NAME.	Assumed Parrallax.	Apparent Semi-axis	Real Semi-axis	Period. (Years.)	Mass Sun's=1.
	"	"			
η Cassiopeae ..	0.15	8.64	57.	195.2	5.0
Sirius	0.38 0.19	8.53	22.4 44.8	44.0	5.8 46.4
α Geminorum.	0.20	7.54	37.7	997.0	0.54
α Centauri . .	0.75	17.50	23.3	77.0	2.14
70 Ophiuchi .	.16	4.79	29.9	94.5	3.0
61 Cygni . . .	0.43	15.40?	35.8?	450.0?	0.23

The mass of Binaries is often, if not always, very great. The star 70 Ophiuchi has a mass three times that of the Sun; while the mass of Sirius and its companion by older determination is 13.7 and 6.7 times respectively the mass of that same unit. The great mass of Binaries is not only a fact, but one of profoundest philosophical significance in the speculation here indulged. For, as previously stated, the existence of great masses would imply the existence of great excentricities; and since both of these actually do exist side by side, we have at once in this coincidence a strong argument for the correctness of our proposition.

LONG PERIODS OF BINARY STARS.

A revolution of some of the Binaries occupies only about 35 years, while the revolutions of others require hundreds and even thousands of years. Gamma Leonis is known to be moving in an ellipse that cannot be described in less than 1200 years. The nearest component of the quadruple star ε Lyrae is just closing its circuit begun in the reign of Alfred the Great, and the most remote component lacks much of complying with a contract let before Chufu reared his monument on the plain of Gizeh, while the revolution of these double components about their common center of mass can only be reckoned by millenniums. But what shall be said of such a star as Theta Orionis? Here a single elliptic circuit compasses all human history—antedating the origin of the Rig Vedas, when, after the terror of night, the rising sun first tinged the rejoicing Hindoo's pallid face with flame. The double stars revolve in elliptic orbits according to Kepler's second law, and hence the law of gravitation holds among the stars the same as in the planetary system. In like manner the other laws of Kepler, as generalized in the theory of gravity, are also valid. Wherefore, by the third law, we should expect long periods if we have great distances. If, therefore, great distances exist, as actually do in a number of cases, long periods are necessary results. But one more explanation is possible—that of small masses. Take the equation

$$M_0 + M = \frac{4\,\Pi\,a^3}{T^2}.$$

It is plain that if $M_0 + M$ be small while a is ordinary, T must at the same time be large. In other words, if the masses are small, even while the distance is not extraordinary, the time of revolution will be

great. Such merely conceivable cases, however, do not seem to occur in nature.

COLOR OF DOUBLE STARS.

PROF. YOUNG'S GENERAL ASTRONOMY:—"In a very large proportion of cases (perhaps about one-third of all) the two stars are nearly equal; in many others they are extremely unequal, a minute star near a large one being usually known as its 'companion.'

"Not infrequently the components of the double stars present a fine contrast of color; *never, however, in cases where they are nearly equal in magnitude.* It is a remarkable fact, as yet wholly unexplained, that where we have such a contrast of color the tint of the smaller star always lies higher in the spectrum than the larger one. The larger one is reddish or yellowish, and the smaller one green or blue, without a single exception among the many hundreds of such couples now known."

TABLE OF 596 BINARIES, (AFTER STRUVE.)

Same color and intensity	375
Same color different intensity	101
Different colors	120

OF 476 OF SAME COLOR.

Pairs White	295
Pairs Yellow or Red	118
Pairs Blue or Bluish	63

When the component parts are of different colors the brighter generally appears to have a tinge of red or yellow; the other of blue or green. Let us examine these data. If we admit, as seems very rational, that the phenomena of color have anything to do with the stage of cooling of the stars, we cannot deny that these data probably indicate real physical laws governing Binary developement. According to

the opinion previously expressed that the Binary components are comparable in magnitude, we should not expect them to differ widely in their stages of developement. For on each component of common origin and temperature the process of cooling would proceed at about the same rate ; and in consequence we should not expect light widely different in character to be given off. Let us now apply the theory of Probabilities to the above data and see if there is reasonable grounds for inferring a law. Take the primary colors as seven : The chance that a component should have any particular one of these colors is 1 -7, the chance that the other will have any particular one of these colors in like manner is 1-7. Now since there are seven colors, the chance that the two components will have the same color is 1-7. If the distribution of color is a matter of chance we should not expect to find any considerable variation from this ratio—that is, about fourteen per cent. of the Binaries ought to have the same color. But as a matter of fact, instead of fourteen per cent. we have from the foregoing table eighty per cent. of these Binaries in which the components are like colored. Instead of eighty-six per cent. of different colors we have only twenty per cent. What a significant result! Can this indicate other than actual physical law governing Binary developement? Furthermore, according to the general law of gaseous cooling propounded by J.s Homer Lane, we should expect that bodies like the stars would get hotter and hotter, contracting under the force of gravity, until such condensation was attained that their particles, within the range of molecular repulsion, were no longer free to move and thus give off ethereal vibrations corresponding with the rapidity of vibrations which ought to have resulted from such contraction and consequent molecular kinetic energy. We should expect, therefore, the more contracted body to give

off the highest vibrations—that is, the blue. According to this conception the later stages of the nebular or gaseous body contracting under the forces of gravity would present the highest temperature. In a system of a large and a small body of this kind, the larger body contracting—and therefore heating—proportionally the slowest, we should expect to find the smaller component, being more advanced in its developement, giving off a blue light, while the larger body was yet giving off a yellow or red light. However, as time went on, the larger body growing ever hotter and hotter, while the smaller was nearing the stage of liquidity, or at least dense fluidity, the red light of the larger body would be quickened to blue. By this time, however, it seems not unlikely that the small component would have begun to darken so as to appear blue from the physiological effect. In the final state there must arrive a time when there must be a balancing between central forces due to attraction and repulsive molecular force due to molecular approach. This repulsive force will be very small in the nebula—somewhat larger in the gaseous form—very much larger in the liquid state. Finally it must cause contraction almost to cease. In the last stage the light emitted may pass from blue to red, but in general it will be feeble, and perhaps on account of faintness may appear blue. The next stage is that of solidity; and lastly dark incrustation will follow. We find it a general rule that the larger components are red or yellow; the smaller being green or blue, a correspondence with the theory above deduced. For since the stars shine by their own light, we cannot reasonably suppose any perceptible per cent. of them to be so far advanced as to be in the last stage—that of dark incrustation. They are, therefore, growing hotter, in particular the larger ones, by the law of gaseous condensation. The above phenomena are,

therefore, in complete accord with our theory and strongly confirmatory of the same. The following is our theoretic curve of color:

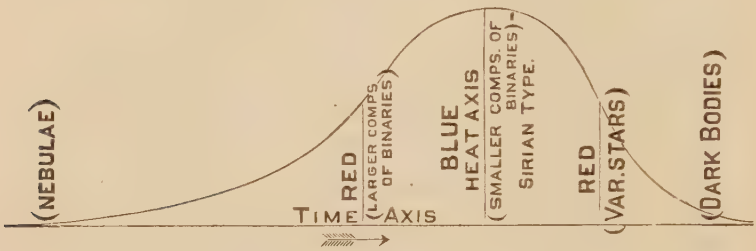

Fig. 6.

THE RED COLOR OF VARIABLE STARS ACCOUNTED FOR ON THIS HYPOTHESIS.

Prof. Newcomb is authority for the statement that eighty per cent. of the variable stars are red, and whilst variable stars do not necessarily come under the domain of this thesis, it may not be without interest to see if they present any phenomena contradictory to the doctrine of color just set forth. If we suppose variable stars are in the last stage of developement—that in which molecular repulsive force begins to balance the force of gravitational contraction and consequent heat—we are naturally led to conclude that here the red color is due to the advanced stage of cosmic developement. And this supposition accords with the present theory of variable stars which regards them as encrusting bodies whose light is subject to variation by outbursts of incandescent hydrogen, magnesium and other gases confined and compressed by their cooling and contracting globes. Accordingly, we look upon the red color of the variable stars as in general different from that presented by the larger components of Binary Stars.

The former have already passed the hottest stage—the blue—and now, in the absorptive stage, advancing toward the stage of incrustation have become red; while the latter have not yet reached the highest temperature, having attained only to the stage of red or yellow in their condensation from their original nebulae. The argument from the theory of Probabilities is here quite as applicable, and, since eighty per cent. of the variable stars are red, showing a real law, quite as strong as in the preceding paragraph. It is worthy of note that out of 42 of the most prominent variable stars only one variable star (α Herculis) appears in Burnham's list of 86 of the most remarkable Binaries. Some of the Binary Stars, however, present peculiar phenomena of light-change. In case of Gamma Virginis it seems to depend upon the distance of the two components, since the fluctuation was greatest at Periastron and grew smaller as the star receded, promising possibly to be entirely obliterated before Apastron is attained in the year 1926. The phenomena of light-variation in the stars seem to be complicated, and perhaps cannot be entirely ascribed to any one cause; yet the above phenomena are just such as we should expect to result from the influence of tides, supposing the stars to be whirling about their axes, and the spots on their surfaces, that give rise to this fluctuation, to be connected with the revolution of the components somewhat like the revolutions of Jupiter, the Earth, and Venus, are supposed to be related to the periodicity of the spots on the Sun. This suggestion completes the speculation on the color of the stars, and, so far as we know at present, in full accord with the laws of Cosmic Physics.

RELATIVE MASS OF BINARY COMPONENTS.

From the Darwinian theory we should expect that the derived spheroids, owing to viscosity and surface tension coupled with fluid adhesion, would be of a magnitude comparable to the magnitude of the remaining spheroid. Plateau's experiment is a good illustration of this. In the case of the Moon, which Darwin has proved in all probability to have originated in this way, we find the masses to be in the ratio of 1 to 80; in the case of Sirius the ratio is 1 to 2, a ratio that is perhaps large, tho' we know of no reason why a ratio of unity might not obtain. This is probably the case with γ Virginis. However, as far as calculations extend, a large ratio seems to exist. By a method based upon one of Kepler's laws this determination of mass is not only possible, but also reliable within the range of errors of observation. The application of this method, however, is very limited. And altho' it gives confirmatory results, we have yet another method which, tho' perhaps not so accurate, is of much wider range of application, and therefore of the greatest value in drawing a general conclusion. This method is that of inferring the relative masses of the Binary stars from their relative magnitudes.

List of the more remarkable Double Stars, compiled by S. W. Burnham:

NAME.	Magnitudes.		Difference.	COLOR—NOTES.
35 Piscium	6.2—	7.8	1.6	White, ≶. Pale white: violet.
38 "	7.0—	8.0	1.0	
42 "	6.8—	10.7	3.9	Yellow: Blue: Green.
51 "	5.0—	9.0	4.0	White: Ashy.
55 "	5.0—	8.2	3.2	Yellow: Deep red.
η Cassiopeae	4.0—	7.6	3.6	Yellow: Purple.
36 Andromedae . .	6.2—	6.8	0.6	Binary, 349.1 years.
Φ Piscium.	4.7	10.1	5.4	White: Blue.
42 Ceti	6 2	7.2	1.0	
Polaris	2.0	9.0	7.0	
ε Sculptoris	6.0	10.0	4.0	White: Dull red.
α Piscium	2.8	3.9	1.1	
γ Andromedae. . .	3.0	5.0	2.0	Yellow: Blue; began double, 0.5.
ι Trianguli	5.0	6.4	1.4	Yellow: Blue.
ι Cassiopeae	4.2	7.1	2.9	A. & B.)
ι Cassiopeae	8.1		3.9	A. & C.)
84 Ceti	6.0	9.2	3.2	Yellow: Ashy.
γ Ceti	3.0	6.8	3.8	Yellow: Blue.
ε Arietis	5.7	6.0	0.3	Binary.
ζ Persei	2.7	9.3	6.6	Light green: Ashy; other small star near.
ε Persei	3.1	8.3	5.2	Pale white: Lilac.
39 Eridani.	6.0	9.1	3.1	Yellow: Blue.
ρ Tauri	5.0	8.0	3.0	Red: Bluish.
ι Orionis	4.7	8.5	3.8	Yellow: Blue.
β Orionis	1.0	8.0	7.0	
23 Orionis	5.0	7.0	2.0	
η Orionis	4.0	5.0	1.0	Discovered by Dawes.
λ Orionis	4.0	6.0	2.0	Yellow: Purple.
σ Orionis	4.1	10.3	6.2	A & B)
σ Orionis		7.4	3.4	A & C)
θ' Orionis				Septuble, in great nebula.
ζ Orionis	2.0	5.7	3.7	Yellow: Light purple.
11 Monocerotis. . .	5.0	5.5	0.5	A & B)
11 Monocerotis . . .		6.0	1.0	A & C)
12 Lyncis	5.2	6.1	0.9	A & B)
11 Lyncis		7.4	2.2	A & C)
56 Aurigae	6.0	9.0	3.0	White: Blue.
μ Canis Maj. . . .	4.7	8.0	3.3	
ζ Geminorum . . .	3.2	8.2	5.0	
Castor	2.7	3.7	1.0	

NAME.	Magnitudes.		Difference.	COLOR—NOTES.
5 Navis	5.3	7.4	2.1	
ζ Cancri	5.0	5.7	0.7	A & B)
Cancri		5.5	0.5	A & C)
38 Lyncis	4.0	6.7	2.7	
γ Leonis	2.0	3.5	1.5	Yellow : Greenish.
35 Sextantis	6.1	7.2	1.1	Yellow : Blue.
ξ Ursae Maj.	4.0	4.9	0.9	Binary.
65 Ursae Maj	6.0	8.3	2.3	Yellow : Blue.
ϱ Comae	6.0	7.5	1.5	Yellow ; Blue.
24 Corniae.	4.7	6.2	1.5	Yellow : Blue.
γ Virginis.	3.0	3.0	0.0	Binary.
35 Comae	5.0	7.8	2.8	A & B)
35 Comae		9.0	4.0	A & C)
84 Virginis	5.8	8.2	2.4	Yellow : Blue.
ξ Boötis	3.5	3.9	0.4	
ε Boötis.	3.0	6.3	3.3	Yellow, blue or green.
ξ Boötis	4.7	6.6	1.9	Yellow: Reddish purple.
44 Boötis	5 2	6.1	0.9	Yellowish : Bluish.
μ Boötis	4.0	6.7	2.7	A & B) Binary.
μ Boötis		7.3	3.3	B & C)
δ Serpentis	3.0	4.0	1.0	Binary.
ξ Librae	4.9	5.2	0.3	A & B)
ξ Librae		7.2	2.3	A & C)
Antares	1.0	7.0	6.0	Red : Green.
36 Ophiuchi	3.0	6.0	0.0	
α Herculis.	3.0	6.1	3.1	Yellow : Emerald.
ρ Herculis.	4.0	5.1	1.1	
70 Ophiuchi.	4.1	6.1	2.0	Yellow: Purple: Binary.
ε^1 Lyrae	4.6	6.3	1.7	) Quadruple.
ε^2 Lyrae	4.9	5.2	0.3	)
ζ Lyrae	4.2	5.5	1.3	
β Cygni	3.0	5.3	2.3	Gold yellow : Blue.
ζ Sagittae	5.7	8.8	3.1	Light green : Blue.
ε Draconis	4.0	7.6	3.6	Yellow : Blue.
θ Sagittae	6.0	8.3	2.3	
49 Cygni	6.0	8.1	2.1	Yellow : Blue.
ε Equilae	5.3	6.2	1.0	A & B)
ε Equilae		7.1	1.9	A, B & C)
12 Aquarii	5.6	7.7	2.1	Yellowish : Blue.
61 Cygni	5.3	5.9	0.6	
β Cephei	3.0	8.0	5.0	Light green : Blue.
41 Aquarii	6.0	7.7	1.7	Yellow : Blue.
53 Aquarii	6.0	6.3	0.3	White : Yellow.
ζ Aquarii	4.0	4.1	0.1	Binary.
ψ Aquarii.	4.5	8.5	4.0	Yellow : Blue.
σ Cassiopeae.	5.4	7.5	2.1	White : Blue.

Average difference of magnitude for 85 stars found to be 2.4.

It would be in vain to hope for very reliable results were not many stars available as the basis of reckoning, and their magnitude and general nature understood. These conditions, however, have been both fulfilled. It is known that the stars generally are bodies like our Sun, some smaller, some immensely larger, all, however, shining by their own light. It is known, furthermore, that there is not in general a range of more than two or three magnitudes between the apparent size of the components of Binaries. In some cases the difference is much greater; often less. But the general fact that Binaries do not differ very widely in apparent size is fully sustained by observation. A profounder significance yet attaches to this fact. Spheroids cool in proportion to the amount of surface exposed, heat potential being equal; that is, as their squared radii. The amount of heat to be given out is directly proportional to the masses, other properties being alike, that is, as their cubed radii. It follows therefore, since the larger spheroid has the greatest volume (and therefore the greatest amount of heat) and proportionally the least amount of surface, that the smaller spheroid will cool and shrink quicker comparatively than the larger spheroid. Wherefore the components of Binaries are more unequal in volume than they really are in mass. Moreover, the greater mass of the larger spheroid will make the force of gravity proportionally more intense at the surface, consequently generating more intense heat, and therefore from the intensity of the light given off the difference in mass will be further exaggerated. Wherefore from these two causes combined it seems extremely probable that the components of Binaries are much more nearly equal than they appear, which is in complete accord with, and strongly confirmatory of, the proposition concerning Binary evolution.

THE APPROACH OF TWO STARS OF SEPARATE ORIGIN COULD NOT GENERALLY THROW THEM INTO ELLIPTIC ORBITS AND CAUSE THEM TO REVOLVE ABOUT A COMMON CENTER OF MASS.

Two such bodies could not assume elliptic orbits except under most extraordinary circumstances. For it is plain that in nearly all cases, considering the immensity of the intervals of space, and the great distance and velocity with which one sun would approach another, a velocity would be acquired too great for the assumption of elliptic orbits. This holds true particularly for large bodies like the stars. But an argument that is yet even more unanswerable is the fact that the components of triple and quadruple stars are known to move nearly in a plane. And there is no reason for supposing these stars to have had an origin different from the Binaries. This thesis deals primarily with Binaries only on account of their vastly superior numbers. When we remember that about one-half of the stars are double, we see that the foregoing proposition, tho' not absolutely exclusive, is general enough to forbid us suggesting such an origin for the millions of Binaries that float throughout the wilderness of space.

SIR WM. HERSCHEL'S AND PROF. PEIRCE'S HYPOTHESIS OF NEBULAR CONDENSATION ABOUT SEVERAL SEPARATE POINTS INADEQUATE TO EXPLAIN THE ORIGIN OF BINARY STARS.

After the foregoing discussion had been written, the writer happened upon the following suggestion of Prof. Benjamin Peirce: "When there are several points of condensation in a nebula making it a double, triple, or multiple nebula, it naturally terminates in the corresponding evolution of a Double, Triple, or Multiple Star." However bold it may seem to criticise the opinion of a mathematician of such masterly

skill as Prof. Peirce, it is certainly the privilege of every one to make a candid search for the hypothesis which will best explain observed phenomena. Let us then carefully examine this hypothesis. Prof. Peirce's suggestion doubtless occurred to him from the appearance of certain planetary and elliptical nebulæ just as a similar idea did to Sir Wm. Herschel a century ago. Planetary nebulæ do, indeed, in some cases, present the appearance of condensation about one, two, or more centers; but these centers of condensation in general appear to follow but little, if any, law of symmetry, neither are they comparable in magnitude.

If the Binary systems have arisen in this way, since they present considerable regularity both in form and in relative star-magnitude, we should naturally expect to find this same regularity in those nebulæ which are to form the Binary stars of the future. Such regularity, however, does not seem really to exist. For whilst it is true that there are planetary nebulæ, in limited numbers, it is not true that any large per cent. of these present that regularity of internal condensation that would lead us to believe that they would ever develope into Binary systems. And these planetary nebulæ being relatively rare, only a small per cent. of all the nebulæ visible present distinct points of central condensation, and still smaller is the per cent. of nebulæ which give the appearance of having double points of condensation. Whilst on the other hand it is true that the Binary stars form a very large per cent. of all the stars in our firmament —from one-third to one-half of the total number according to the estimation of Struve.

Furthermore, granting for argument's sake that nebulæ physically connected actually exist, and that they present two centers of condensation, let us now inquire whether these conditions could in general give

rise to Binary evolution. These centers would be as it were dense parts of one common mass. And approaching each other under the influence of mutual attraction, they would drag with them the rest of the outlying chaos. These nebular bodies would therefore slowly approach each other, and unless materially influenced by the attraction of outside bodies (which we could not generally suppose to be the case, owing to the immense intervals of celestial spaces), they would move on a straight line joining the centers of mass of the two nebular bodies. The almost-inevitable result of the mutual attraction and consequent motion of two nebular masses will be collision; and altho' the chance of the impact being actually central is infinitely small, yet the chance of its being about central is really very great. The two bodies will therefore in general penetrate each other, and the impact will give rise to heat and rotary motion. What will be the result of the rotation thus inaugurated? Clearly the denser matter—that is, the centers of nebular condensation—will gradually settle towards the common center and the rest of the nebula will take the form of a spheroid, successive layers being arranged in the order of their respective densities. As the rotation continues, the spheroid will flatten out into a discoid, most dense and intensely heated at the center. The contraction at this stage of the process will be solely from the direction of the poles, each particle falling not towards the center of the mass, but towards the plane of the periphery.

Now one thing is sure, and that is: If a Binary star originates from this rotating spheroid resulting from the collision of two centers of nebular condensation under the force of gravity, it must originate from an evolution of this common fiery mass. One question yet remains: Will the resulting evolution be Laplacean or Darwinian? And our answer, also

given elsewhere, is that it will generally be Darwinian. Prof. Peirce's hypothesis is therefore untenable. Now in addition to the reason above assigned—namely, that if condensation began at separate points of the same nebula, these several agglomerated centers would finally fall together, impinge and become the center of one discoid—the Binary stars are too close together to have been formed from separate nebulæ; and a reason has already been given why two suns of separate origin could not in general assume elliptic orbits by mutual approach.

But grounds perhaps equally solid for rejecting Prof. Pierce's hypothesis are found in the motion of the Triple stars. Here we have systems of three bodies revolving in the same direction and very nearly in one common plane. This is the case with several of the most important Triple stars, such as ζ Cancri, Σ 2481, ε Equilie, and Σ 2479, and this principle is therefore believed to be true for all triple and multiple stars, altho' it may require ages for observation to establish it incontestably.* And there is every reason to believe that these triple and multiple systems have had an origin like the Binary systems. For if

* To this end we are personally indebted to Prof. Young for the following data: Flammarion's Catalogue contains 819 objects, and it gives all the multiple stars in which any orbital motion had been detected up to 1878. It contains 73 triple stars, of which just about one-half are certainly not *ternary*, *i. e.* one at least of the components is merely optically connected with the others, and has an independent motion. Of the remainder the ternary connection is still undecided for about 14 or 15, leaving only about the same number (14) in which it is either certain or quite probable.

Table (A) Certain Ternaries.

(The motions marked + are clockwise;— counter clockwise.)

NAME.	Components.	Motion.	Components.	Motion.
ζ Cancri . . .	A B	—	A B | C	—
Σ 2481	A B	—	A B | C	—
ε Equilie . . .	A B	—? rectilinear.	A B | C	—
Σ 2749	A B	+	A B | C	+
ζ Scorpii . .	A B	+	A B | C	—

Table (B) Extremely Probable Ternaries.

Σ 183	A B	—	A B | C	+ but doubtful.
Σ 719	A B	+	A B | C	+ "
Σ 1001	Results	discordant, nothing certain.		
Σ 1426	A B	+	A B | C	+
$O\,\Sigma$ 276 . . .	A B	—?	A C	+
Σ 2006	A B	—?	A C	—
Σ 2479	A B	—	A C	—? ob. discord.
x Aquilae . .	A B	=|= uncer.	A C	=|= (uncer.)
Σ 2607	A B	—	A C	" " motion very slow

Quadruple Stars.

ε Lyrae.	A B motion of	— AB | CD	C D not cer	— tain, but probably —.
ν Scorpii . . .	A B motion of	prob'y + AB | CD	C D is +.	+

It is plain that here we have a preponderance of evidence in favor of the theory that the components of triple and quadruple stars move in a common direction; and the observations will no doubt show that their orbits lie about in one plane. ζ Scorpii is the only settled exception to this rule and it may be that some error has there crept in, which may hereafter be detected. Whilst common motion is quite probable, and perhaps in general theoretically necessary, its existence can only be made *certain* by time, as these motions are extremely slow.

Prof. Peirce's hypothesis be considered, we see at once that we should naturally expect to find bodies not even revolving in the same direction, much less in the same plane. We should as naturally expect to find the planes of the orbits of the different bodies perpendicular to one another as parallel and coincident. Such chance phenomena, however, as far as our present knowledge goes, do not really exist. From our reasoning it seems, therefore, almost certain that Prof. Peirce's suggestion cannot be applied to Binary and Multiple stars, altho' possibly to those glorious clusters and vast star-systems which have a common "drift", whose origin as systems, however, is certainly quite distinct from that of Binary, Triple, and Multiple stars.

GENERAL SCHOLIUM.

From Theorem II. we see that a body revolving in an elliptic orbit is pulled sidewise by a part of the tidal component, and hence there is a tendency to revolve the orbit in space. We should therefore expect, if observations could be made sufficiently accurate, to find that the orbits of Binaries turn secularly rapidly about their common center of mass. This component would be more and more potent as the orbit becomes the more excentric. The rate of progression of the line of the Apsides would thus become ever greater and greater as the excentricity increased.

UNEXPLAINED MOTION OF MERCURY.

The Perihelion of Mercury has an unexplained motion forward on the ecliptic amounting to $50''$ per century. Hitherto it has been hoped that some inner planet might be found that would explain this anomalous phenomenon; but as such a planet is now known almost to a certainty not to exist, it may be allowed, if not too bold a conjecture, that tidal influence

may be important in determining this motion. And altho' no calculation has been made, nor indeed is it known how a definite calculation could be made, it is certainly as plausible a theory as the one which falls back on the matter around the sun for the cause of this motion, especially when we consider the great power of the sun, its mobility, together with the rapid motion of Mercury and the great excentricity of its orbit. The present motion may (according to Cor. 2, Th. II.) be regarded as the accumulated motion of ages.

IF PLANETS ENCIRCLE THE COMPONENTS OF BINARIES, THEY HAVE ORIGINATED BY THE DARWINIAN PROCESS.

Supposing our hypothesis concerning the origin of Binaries valid, this is almost a necessary result. If Darwinian evolution brought about a Binary system, planets in that system could only be formed by the same process. For the stage for Laplacean evolution would then have been long since passed. The two components would now be glowing plastic suns, capable of further planetary evolution only by the Darwinian process. The physical vicissitudes to which planets in the Binary systems would be subjected are extremely great owing to the great excentricities of their orbits.

ULTIMATE TENDENCY OF A STAR-SYSTEM.

The ultimate tendency of a system of Binary stars revolving about a common center of mass can be easily traced. If a system be operated upon as we have supposed, it is plain that eventually synchronism must be attained between axial rotation and orbital revolution. When this is the case, the two bodies will no longer recede from each other by the component of tidal friction; for then it will no longer exist. But the bodies thus relatively at rest will move on in their orbits in an equilibrium dynamically

unstable. If a slight force from the center of mass of another system be exerted upon the delicately-balanced system the tidal component will be turned in the other direction. The tidal axis will now point behind the companion in its orbit, and there will thus arise a component tending to pull the companion to the parent mass. It will then gradually wind down on a spiral and collision between the two is inevitable. The components on both bodies join in this common tendency, and conspire together to bring about a retracing of the steps taken in the developement. When collision shall have taken place, there will remain another cycle of evolution to be completed in a manner analogous to that first traced. It should be stated that in this winding-up of the system the tendency of the tidal component is to decrease constantly the excentricity of the orbit. Such, then, is the course of cosmic evolution. The same grinding of wheels that developes the system is the cause of its decay. In all these processes, however, it should be remembered, there is a constant dissipation of energy into the lowest form—heat. So the future of the cosmic system is one of heat—uniform temperature throughout—but without molar motion. This process is eternal and transcending; it is the cosmic cycle, leading to an ultimate finality to the whole cosmic system, if the present physical laws continue to exist. But whether natural laws are changeless is a question which necessarily transcends the domain of human knowledge.

NEW LIGHT THROWN UPON COSMIC PHILOSOPHY.

If the course of evolution be true which we have traced for the Binary stars, our ideas on cosmogony must undergo an important modification. For altho' the above theory is not shown to be in every case the only theory that suffices to explain the observed phenomena, still any other is very improb-

able. Now, when we remember that about one-third or one-half of all the stars are estimated by Struve, an illustrious authority, to be physically connected, and that this number, say from 25 to 50 millions of the stars, have been thus formed, our conception of the cosmologic importance of the foregoing theory is very much enlarged. In rising to the contemplation of such a conception we look, as it were, from the center of the milky way out upon the limitless fields of creation—an ocean of space strewn with blazing spheres as with islands, a conception so grand that when we look down upon the earth, we see it a mere point, and feel bashed that our Republic no longer visible does not shine with that sirian lustre that characterizes it here upon earth. If we be correct, then, that both plans of developement hold in nature, we see at once enthroned in might in the glittering blaze of the heavens two mighty monarchs; monarchs whose empire is the cosmos. The universe has thus two vast foundries that mould from star dust by different processes the great wheels of nature and send them whirling along their paths; but worn in their endless race by tidal friction while propelling the universe on to old age they all at last meet the same ultimate fate. Melted in a common foundry they are again moulded into new worlds, and on, while matter, energy, space and time endure, rolls the cosmic cycle.

Then let this thesis, extending Prof. Darwin's theory of tidal evolution to those vast systems of Double Suns that float away in the blue depths of the firmament, be brought to an appropriate close by a passage, no more poetic than scientific, from Erasmus Darwin, the distinguished Ancestor of the Prince of Naturalists, and Grand-father of our illustrious Cosmogonist:

"Star after Star from heaven's bright arch shall rush,
Suns sink on Suns, and systems systems crush;
Headlong, extinct, to one dark center fall,
And night and death and chaos mingle all—
Till o'er the wreck, emerging from the storm,
Immortal Nature lifts her changeful form;
Mounts from her funeral pyre on wings of flame,
And soars and shines, another and—the same."

EPITHESIS.

"THE HEAVENS DECLARE THE GLORY OF GOD."

From the most ancient times man has been wont to contemplate the heavens. The dome of the firmament and the spheres that harmoniously glide through high heaven's "brass-paved way" have been the subject of wonder and admiration in all ages. The ancient Greeks were so impressed with the beauties of the external world that they called it the cosmos. This word cosmos itself means the beautiful and the orderly. Law and order are stamped upon the face of heaven. To a calm and considerate mind contemplating the vault above, they are revealed in the grouping of the stars.

The magnitude of the heavenly bodies, the grandeur of the system to which they belong, the immensity of the celestial spaces all remind us of the finity of our surroundings, and of the incomprehensibility of the system of the world. The earth is 8,000 miles in diameter, the sun is 800,000 miles; some of the fixed stars are doubtless thousands of times as large as our sun, and some of the nebulae may be as great as our whole stellar system; the sun is 93,000,000 miles from the earth; the nearest fixed star 19,000,000,000,000 miles; and the nebulae and other fixed stars many thousand times as far. Telescopic power is finite; and yet, with such limited means, one hundred million stars, like our sun, are brought within the range of our vision. All of these

stars, we are told, are suns; suns similar to our own—some in an early stage of developement, nebulous stars—some fully developed, doubtless the centers of retinues of planets, like our own sun—some already senescent, with planets cold in death like our moon. Such is the cosmic process. Its silent and everlasting march among the worlds reminds us of the procession of life and death among men and nations.

While we ponder on the origin of the Binary Stars, and study their constitution and history, or turn to our material occupation, 'our very firmament is careering in infinite space.' The earth moves sixty-eight thousand miles per hour in its orbit; the sun and its attendant planets are hourly sweeping thro' immensity towards the constellation Hercules fifty thousand miles; from age to age the stars, like a swarming hive of bees, are in constant motion among themselves; the great stellar system may itself have motion of which we can never know. The astronomer looks in silent awe upon the 'eternal waltz of cosmic dancers'—a system of satellites—a system of planets, including the earth—a system of stars, including our sun. How sublime a conception! Let us then exclaim with the Psalmist: "Lord, thou hast been our asylum in all generations. Before the mountains were brought forth, or ever thou hadst formed the earth and the world, even from everlasting to everlasting thou art God."

The resources of the universe suffice for the devolution of a chain of cosmic order without limit. 'The infinitude of creation could spare a world or a milky way as easily as a flower or an insect.' How grand a thought! We turn the microscope to the earth to survey the minute worlds of beauty and of order; but we turn the telescope to the heavens and attempt to sound the depths of unfathomable space. But in vain. The bounds of the universe recede with the

increase of telescopic power. Ever-widening fields of space stretch out before us and tempt us to their exploration, while the depths of the firmamental ocean remain unsounded. Truthfully, then, did Cicero relate the dream of Scipio, who said in contemplating the earth from the milky way: "There was a dazzling circle of flaming stars; their magnitudes were such as we never imagined. The globular bodies of the stars so greatly exceeded the magnitude of the earth—the abode of the human race—that I was ashamed to see the contrast of our Empire, as it were, only a point."

Beyond the utmost bounds of the universe, beyond the regions of the remotest nebulae, where a ray of light from the stellar universe has never yet fallen, there lie the countless germs of future worlds and systems, now for the first time breaking the midnight silence of eternity and putting into existence the first ruddy glow of light.

The law of gravitation, so far as we know at present, holds to the utmost bounds of material creation. The laws of heat, chemical combinations, electricity, light, magnetism, inertia, and motion, are equally general; or to be brief, laws are universal in the cosmos. The flashing lightning, the flaming meteor, the dykes and mountains of the earth and of the moon, the glowing avalanche of lava, the fire-belching volcano, the clouds that envelope the earth, the planets, and the sun; that beautiful system of planets that floats light-poised in the blue ocean of space; the fiery comets—those erratic visitors that pass from star to star, weaving material existence into unity—the stars, double, triple, and multiple, periodic, variable, and constant, each fulfilling its predestined orbit, the nebulae, annular, spiral, and irregular, each moving toward a higher state of cosmic existence, the firmament itself—our sun in the

center and the nebulae on either side of this stellar stratum—the whole living cosmos as revealed in the most powerful telescope, proclaims the dominion of law and order throughout all immensity.

With the spectroscope we determine the elements of the earth, the composition of our sun, and all the hosts of other suns that form our stellar system, in which we witness every stage in cosmic evolution, from those cooled and encrusted bodies occasionally rendered luminous by the outburst of igneous matter, known as variable stars—to the stage of nebular incandescence. The fragments of nebulae, comets, and meteors—world-stuff scattered throughout the wilderness of space—'are all flaming messengers bringing us tidings that we are not, as had been thought, isolated from the starry realm. They declare that the natural government which reigns imperial here upon earth is loyally recognized in those ulterior provinces that lie on the distant verge of the visible universe.'

We have not assumed that there are other worlds than ours. But the analogies of nature lead us to conclude that other planets of our system either have been, are now, or at some future time will be, inhabited. Intelligences need not conform to the human type; for this is not absolute. But whatever may be their form of being or environments, their natures cannot escape the limitations of the physical properties of matter. It is sometimes said that such intelligences would interpret the universe on the same principles of logic and mathematic as are known to us. But this by no means follows. For we know not what may be their perception of space. We intuit space as of three dimensions. But mathematicians have not only made it plain that spaces of higher dimensions *may* possibly exist; recent researches of

geometers have even lent probability to the hypothesis of such higher spaces.

However this may be, and whatever may be the nature of these beings—if they only have a perception of the existing order of things—we venture to conjecture that they would say with the inhabiters of earth: "The heavens are lauding the glory of God, the firmanent proclaiming the work of his hands; day unto day uttereth speech, and night unto night showeth knowledge. There is no speech nor language, their voice is unheard. Their line has gone out through all the earth, and their words to the end of the world." When we turn the spectroscope to the nebulæ, all that have been resolved give spectra identical with our sun and the ordinary fixed stars. This result shows that the resolvable nebulæ are what Sir Wm. Herschel suggested, vast clusters of stars analogous to those of 47 Toucani and Ω Centauri of the southern heavens, two most glorious globular clusters, intensified by innumerable stars at the center to a perfect blaze. What unspeakable glories here disclosed thro' this invention of human genius! Here let us pause, then, to picture to ourselves in the light of this revelation thousands upon thousands, yea, millions upon millions of other star clusters, each with its constellations, its colored, periodic, variable and double stars, its numberless, dark, unseen, but probably habitable planets, floating away in immensity, each with its satellites and tides, its mountains and valleys, its rivers and oceans, under the common reign of a single empire whose ministers are heat, light, electricity, ether, and gravitation.

Glance back thro' the ages and behold the universe a confused reign of chaos—cold—primeval darkness. See the slow aggregation of particles about centers, the germs of future nebulæ, of stars, and of clusters; behold the solar system, a mass of star-dust,

the planets yet unformed; but pursue the solar nebula in its condensation, till it becomes a disc-shaped spheroid, soon leaving rings of vapor to form the planets, these in turn to form the satellites. Here we catch the first glimpse of the earth. Gaze upon the fiery moon near the earth raising tides mountain-high, and the thinly encrusted globe beginning to be crumpled, folded, and flexed to form the complicated strata of the earth's crust. Examine the first life and mark its simplicity; trace it thro' succeeding ages and note the ever-increasing complexity of functions and of organs both in the vegital and the animal kingdom. But be not unmindful of the changes in the physical condition of the earth—heat, light, water, and air. Review the Paleozoic ages—the ages of mollusks, of fishes, of acrogens, of amphibians, and of coal plants—when the air was loaded with dense clouds of vapor and carbon dioxide, when the absence of solar light made the existence of flowering plants impossible.

Glance along the Mesozoic age, the age of reptiles—the age in which we can truthfully imagine the earth rent with terrific storms and see the heavens lurid with lightning filled with horrible flying reptiles. Pass on to the Cenozoic age—the age of mammals—preparing the way for man. Behold the periods of human history, and of recent formations. View the whole line of developement both in the vegital and animal kingdoms and remember the vast convulsions that mark the close of each era in the evolution of the earth. Survey the progress of human history, especially the progress of the human mind, seeing its errors retreat before the ever quickening advance of human knowledge. Do not all these things tell us, that throughout time and space law and order wear the purple and wield the imperial sceptre over the domain of the visible world?

And now, remembering that we have thus briefly traced the history of our planet; and that our sun is only one of the stars of our galaxy, many of which are probably encircled by planets, have been, are now, or will at some future time be, inhabited by intelligences, does it not seem that such a universal coördination of things is the work of one eternal Process? Truly all things are decreed of Heaven.

The material universe bears the unmistakable impress of Heaven's highest decree—the Cosmic Process—even to the utmost verge of fathomed space, and likewise apparently throughout all past ages.

While the sun pursues his journey thro' the sky, the mighty wheels of fate move slowly on, remorseless and resistless. Organic Nature's fundamental law is, "The Survival of the Fittest." And man, like the rest of created beings, must bow to Nature's will, the decrees of Heaven, the eternal and all-transcending Cosmic Process.

"τεάν, Ζεῦ, δύνασιν τίς ἀνδρῶν ὑπερβασία κατ-
ἀσχοι,
τὰν οὔθ' ὕπνος αἱρεῖ ποθ' ὁ πανταγρεὺς οὔτ'
ἀκάματοι θέοντες μῆνες, ἀγήρως δὲ χρόνῳ
δυνάστας κατέχεις Ὀλύμπου μαρμαρόεσσαν
αἴγλαν."

(O, Zeus, what daring pride of mortals can restrain thy power, which neither the sleep that leads the universe to old age ever seizes, nor the months running on unwearied; but never growing old, enthroned in might, thou dwellest in the glittering blaze of Heaven.)

From the survey we have taken of the universe, we obtain an outlook upon the limitless fields of creation which is difficult to efface from our minds. When we consider Newcomb's scheme of the probable arrangement of the visible universe, drawn from the

researches of Herschel and Struve on the structure of the heavens, we see at one glance all spherical immensity, and this impression is only deepened. Across the center of infinitude is spread the galactic region, wrapt about close on either side by the regions of the nebulae. This galaxy may be a ring, or it may be a stratum one-tenth as thick as it is wide, disc-like in form. Throughout this region of space the stars of our firmament are scattered and agglomerated into clusters. On either side of this glittering lens we see the slowly moving nebulae. Transcendent vision! The "music of the spheres" rolls in sweetest melody throughout this region of space and is echoed by the nebulae above and below. It seems that the cosmos first began to organize in this flat region of space spread out across immensity. For here we find the highest forms of cosmic developement. In accordance with the Riemannian conception of space, if we may be allowed a conjecture, the stellar space may differ from that of the nebular regions. This arrangement of the cosmos may be due to the nature and properties of our space; the flat space of the galactic region may have superimposed upon it a curved space in the regions of the nebulae. Whether this suggestion be of any worth is a question that must await the development of the higher forms of Non-Euclidian Geometry; but meanwhile Geometers may work in the firm conviction that a sublimer problem than that of determining the structure of the heavens and the nature of our space has never occupied the human mind.

The theology revealed in the living cosmos is a true theology; but equally true is the theology that was revealed to the ancients. The lapse of three thousand years does not change immutable truth. For the Psalmist, the testimony of the ages, the living evidence of the universe all declares, "A thousand

years in Thy sight are but as a watch in the night, and as yesterday when it is passed." They are all revelations of Him "Who covereth himself with light as with a garment, who stretcheth out the heavens like a curtain, who laid the foundation of the earth that it might not be moved forever, who covereth it with the deep as with a vesture, who rebuketh the waters and they flee, who thundereth and they hasten away, and the mountains appear, who looketh upon the earth and it trembleth, who toucheth the mountains and they smoke."

The cosmical fabric, thro' its immeasurable magnitude and the endless variety and beauty which shine forth on all sides, impresses us with silent awe. Contemplating the dome of the heavens with the earth as a footstool we can read on the celestial sphere, "The Heavens declare the Glory of God, and the Firmament showeth his Handiwork." From the survey we have taken of the universe in no mean flight, it appears that the ever-ascending world-systems have no end; with uncovered heads we contemplate the material creation in its beauty, continuity, and unity. Sail if you please to the regions of the nebulae where worlds rise into being upon worlds in endless ascension; and 'beyond the outer verge of the widest realm of order, confusion and chaos still contend on a field as limitless as if the works of creation had not already attained a measureless developement.'

Assign whatever diameter you please to the completed creation, we are always near the middle point; but beyond the periphery of the sphere throughout the infinite expanse lie buried in the stillness of night the germs of order, awaiting the progress of eternity to be quickened into active life. So cosmical organization extends itself.

The decay of worlds is only a part of the universal order which brings plants, animals, and man himself

to destruction, only to be succeeded by new organisms at some other point.

But the present order that animates the starry system must come to an end; the sun will be extinguished in darkness. By the influence of cosmic tides a precipitation together of moon, planets, and stars must eventually take place. The crashing of dark bodies defunct thro' cosmic decay will generate enormous heat, reducing them to nebulous dust, and, dissolving the bonds of matter, will expand its constituent elements again throughout the vast space before engirt with the fiery girdles of the firmament, and thus new worlds will be formed. And altho' a reorganization of the precipitated matter must take place, developing each time grander systems as the number of systems decreases; yet the "dissipation of energy" must sooner or later bring all the matter of our universe to one uniformly heated mass. After this, no molar motion, no physical phenomena, but eternal sameness will reign supreme. Such is the destiny of the universe if the present physical laws continue in operation; but this result is based upon the assumption that the laws of the universe are absolutely unchangeable. They are apparently the same, yesterday, to-day, and forever. Whether a change in the laws of energy will take place as we pass thro' the cycle of developement, by which our physical system may be perpetuated, is a problem for the speculator, not for the scientist. Men have observed the heavens from the most ancient times, and thus witnessed the play of a brief scene in cosmic history; and the denial that this history stretches back into prehistoric time thro' the geological eras, and even back through the countless millions of ages, lost in eternity before the earth and the rest of the solar system had begun to form, before the stars had put forth the first rays of light, as matter

began to condense about centers to form the stellar system, and the nebulæ that lie beyond the reach of the telescope; and that it will likewise extend into the future when the earth shall have become cold and lifeless like the moon, when the sun, and fixed stars shall become dark and encrusted like planets, the planets and satellites of our system,—our sun and all the fixed stars—shall have fallen together, and after myriads of successive evolutions become one uniformly heated dead and silent mass, is a folly only equaled by that of a man who would stand on the beach of the Pacific and declare the ocean rolled not beyond the range of his vision.

Let us consider for a moment the physical vicissitudes to which life would be subjected on planets in a system so excentric as γ Virginis. The planets of these primaries, if such exist, would all the time be exposed to the heat of two suns, at one time both very near, at another time one near and the other extremely distant. If in addition to the changes which depend upon the excentricities of the stellar orbits, we suppose the planetary orbits very excentric, as we should naturally expect them to be, we see at once that these vicissitudes will be much augmented. Add to these physical consequences the phenomena of color, components of Binaries frequently being of different and complementary colors, and we have varying beauties which even the poet's fancy is powerless to paint--'days illuminated by rosy or crimson suns and nights lighted up by blue or green ones, and days which two differently-colored suns combine to vivify, preceded by a golden twilight and an azure dawn.' Glories unspeakable! Transferred in imagination to one of these Binary worlds at early dawn, and impressed with the grandeur and beauty of the coming day, the chorus of Sophocles invades our minds:

ἀκτὶς ἀελίου,
τὸ κάλλιστον ἑπταπύλῳ φανὲν Θήβᾳ τῶν προ
τέρων φάος,
ἐφάνθης ποτ', ὦ χρυσέας ἁμέρας βλέφαρον.

(Beam of the sun, of light the most beautiful that hath ever yet shown at seven-gated Thebes, at last thou hast appeared, Oh eye of golden day!)

There also, as here upon the earth, all the beauties of the cosmos appear. We find that a common hand arched the skies, established the mountains, and girt us about with the ocean. And seeing the firmament overflowing with splendor, and the stars glittering in the revolving dome, we exclaim with the Psalmist of old:

"The heavens are lauding the glory of God,
The firmament proclaiming the work of His hands."

HISTORY OF ASTRONOMY.

ASTRONOMY is the most ancient of the physical sciences. And no wonder, since no part of the cosmos presents so grand a field for contemplation as the visible heavens. The beauty, the order, and the regular changes in the aspect of the heavens accompanying the changes of seasons, naturally drew to themselves the earnest regard of the earliest dwellers on earth.

Astronomy, moreover, is no less distinguished from other physical sciences by its slow, but continuous developement from the earliest ages down to the present time; and its growth has been marked by almost as many theories as there have been great geniuses devoted to its culture. In the following sketch, to the regret of the writer, necessarily quite limited, these epoch-making theories will be allowed to determine the divisions of the subject.

I.—AGES OF ASTROLOGY.

This period stretches from the remotest ages down to the time when systematic observations began to be made. It was in its course that there originated the many myths so closely associated with the early history of the Aryan race. These myths, in general, arose from an inability to explain the phenomena of nature without some personification to make them comprehensible. To the phenomena of nature they attributed a spiritual existence, doubtless after the analogy

of the spirit which they conceived to animate living bodies. Under this system of personification grew up vast legends which constitute Mythology and Astrology.

Astrology continued to flourish for many centuries, and is historically closely related to its more rational offspring, Astronomy. During the ages of Astrology, observations of the heavenly bodies were made mainly for the purpose of ascertaining the return of seasons and feast-times, both of which have interested the human race from the dawn of history. Only the apparent positions and motions, however, were observed.

The Indians, of whom we have the most ancient records, have, it is true, a tradition, tho' it is enveloped in darkness, relating to the conjunction of all the planets, B. C. 3102. They have also another period reaching back 1491 years before our era. But there is reason to believe that these periods were not actually derived from observation, but from calculating backward. However, even this knowledge of the planetary motions implies an advanced state of astronomical science among the Indians at a very early date. And this argument is rendered the more plausible when we remember that the Hindoos invented the arithmetical system of notation, expressing all numbers in ten characters; a system, the facility and subtility of which we can with difficulty appreciate; a system too sublime for the genius of Archimedes and Appolonius, two of the greatest men of antiquity; a system of inherent merit, so great, tho' possibly not the greatest, as to insure it a permanent place among inventions of the very first rank.

The annals of the Chinese date from a very early period. This people may have cultivated the science of astronomy even before it was cultivated in India. The first eclipses of which mention is made, can not be

used in chronology, because of the indeterminate manner in which they are detailed. It is evident, nevertheless, that the Emperor Yaou, who lived more than 2000 years before our era, encouraged astronomy, the calendar and the announcement of the eclipses being thought so important that a mathematical tribunal was created so that the more remarkable apparitions of the heavens might be observed with proper ceremonies. Time was measured by means of the Clepsydra, the passage of stars over the meridian was observed, and the angular and lunar distances of the stars were measured. By the Gnomon the summer and winter solstices were determined, and the beginning of the year placed at the latter. The year was known to be about 365 1-4 days in length, and was divided according to a convenient calendar. We know that many other excellent observations were made under the Emperor Tcheon Kong; and three that have come down to us are of inestimable value because of their great antiquity. Two of them give the meridian lengths of the Gnomon which were observed in Loyang; and they assign an obliquity to the ecliptic at this epoch which perfectly accords with the theory of universal gravitation. But Chi Hoanti, about B. C. 213, burned the records of eclipses and destroyed the last vestige of the ancient methods of computation; with these records perished also many valuable observations—all given to flames lighted by the hands of a despot.

In order, therefore, to find observations that may be useful to astronomers, it is necessary to descend to about the 8th century before our era, and pass over to Chaldea. Ptolemy has transmitted to us the records of three eclipses of the moon observed in Babylon in the years 719 and 720 before our era. These have been of the utmost importance in determining the motion of the moon and in finding its secular acceleration. The Priests of Babylon had been observing the

heavens for ages. Under such a sky as that of Chaldea, very excellent opportunity for observation was afforded. The Chaldeans discovered the Saros, and made use of it in predicting eclipses. The ingenious manner in which the principal lunar inequalities were computed shows that very extended and very careful observations must have been made.

We have very little positive knowledge respecting the astronomy of the EGYPTIANS. The situation of the Pyramids gives some color to the belief that there was also an astronomical purpose in their construction. It is rather surprising that the astronomers of Alexandria had to go to the Chaldeans for observations, presumably because either the Egyptians did not have them, or were unwilling to communicate them thro' jealousy of the royal favor that might thus be awakened for the school which the Alexandrians had founded. But Egypt, in learning and in science, stood in very high repute among the scholars of the world; the Egyptains had attracted to their country the greatest philosophers of Greece. Thales, Pythagoras, Eudoxus, and Plato, each came thither for the knowledge with which they enriched their native country. It was then the custom to travel in Egypt before teaching at home. But in both Chaldea and Egypt astronomy was cultivated mainly in the temples by the priests, who made no other use of their knowledge than to consolidate the empire of superstition, of which they themselves were the ministers. They carefully disguised their science under emblems which presented to credulous ignorance heroes and gods, whose actions were nothing but allegories of the phenomena of nature ; allegories which the power of imitation, one of the most subtile influences in the moral world, has perpetuated to our day and mingled with our religious institutions.

Man being induced by the illusion of the senses

to consider himself the center of the universe, it was not difficult, considering his natural desire, to induce him to try to penetrate into the future, and persuade him that the stars influenced his destiny. Thus was the great system of astrology founded; a system requiring much study from its absurdity and complexity, perpetuated, however, by ignorance and credulity almost to our own time. The classic GREEKS, a people so prone to speculate, produced not one great observer. To them astronomy was a science wholly speculative; a science closely resembling what we now call cosmogony, often made ridiculous by the most baseless conjectures. But Thales, born at Miletus in 640 B. C., taught the sphericity of the earth, the obliquity of the elliptic, and the true causes of eclipses of the sun and moon. He was succeeded by Anaximander, who invented the gnomon and geographical chart. Pythagoras, one of the most learned men of antiquity, held the true theory of the solar system, regarding the earth, together with all the planets, and even the comets, as moving round the sun as a center. His school taught that the planets, and even the comets themselves, move round the sun; that the stars are suns, distributed in space, members of the milky way and centers of planetary systems, as can be seen from Cicero's Somnium Scipionis. The theory of the crystalline spheres, tho' sometimes ascribed to Pythagoras, perhaps belongs to some earlier writer.

II.—PTOLEMAIC SYSTEM.

In the school of ALEXANDRIA we see for the first time a connected series of observations; angular distances were measured, and calculations were made by Trigonometrical methods. The positions of the fixed stars were determined, and the paths of the planets traced. Ptolemy Soter received Upper Egypt as his

part of the Empire of Alexander on the latter's death, and attracted to Alexandria, his capital, by his munificence and love of the sciences, a great number of the most illustrious men of Greece. Ptolemy Philadelphus, inheriting his father's scientific zeal, established these illustrious men under his protection, built a magnificent observatory, and caused to be collected, at vast trouble and expense, the most splendid library of antiquity. Here the philosophers worked incessantly, and the impulse given to science is known as the epoch of the Ptolemies, one of the most memorable in the history of the human mind.

Arystillus and Timocharis, the first observers of the school, about 300 B. C., observed the principal stars of the zodiac, thus enabling Hipparchus to discover the procession of the equinoxes. Aristarchus next tried to find the relative distances of the sun and moon, and most ingeniously, but failed to attain satisfactory results. Nearly all his writings have been lost. Hipparchus, justly called the "Newton of antiquity," because of the scientific spirit that pervades all his writings, flourished in the second century B. C. An astronomer of rare skill, of great sagacity, and a sincere friend of truth, he at once determined not to admit any results but those founded on new examinations of former records, or on new observations more accurate than those of his predecessors. He found the length of the year to be 365 1-4 days, with a day to be subtracted every 300 years. He found the inclination of the lunar orbit, and its excentricity, and from observations discovered the motion and the period of revolution of the moon's nodes. A new star appeared, and this led him to catalogue the stars, to enable posterity to recognize any changes that might take place in the heavens. He made many observations on the planets; but unable to explain all their phenomena by rational theories, he left his observations to Ptolemy,

his most illustrious successor. To Hipparchus we owe also the invention and application of spherical trigonometry. For our knowledge of him we are indebted to Ptolemy, as well as for most of our knowledge regarding the ancient astronomy. Before proceeding we must mention the reform of the calendar by Julius Cæsar, assisted by Sosthenes of Alexandria. Ptolemy flourished about 130 A. D., and has left us the *Almagest*, a great work setting forth his system,—a bible, as it were, of ancient astronomy; a work which was indisputable authority for fourteen centuries. The principal points of this system are briefly these: The heavens and the earth are spherical, the latter quiescent in the center of the celestial spheres, only a point in comparison to the magnitude of the universe; circular or spherical, too, is the motion of the heavenly bodies, planetary motion being cyclic or epicyclic,—apparent motions being taken for real.

Ptolemy was greatly indebted to Hipparchus, both for ideas and for observations; but his works on optics, mechanics, etc., and his acknowledgments to Hipparchus, insure him distinction and justify him from the charge of making undue appropriation of the labors of his distinguished predecessor. As the Roman Empire, never illustrious for its cultivation of science, produced no astronomers, henceforth this science soon declined and was given over to the Arabs, by whom it was preserved during the ages of darkness.

The library of Alexandria, the most splendid of the ancient world, was burned by the fanatical Arabs. In vain the philosopher Philopomes exerted himself for its preservation; Omar replied: "If these books are conformable to the Koran they are useless; if they are contrary to it, they are detestable." However, the Arabs soon devoted themselves to letters and science and perceived their irreparable loss—a treasure

of erudition and of genius had been wantonly assigned to the flames—a great sun of the intellectual heavens had been extinguished in midnight darkness forever. About the middle of the eighth century they attained much celebrity for the cultivation of astronomy, under the famous Aaron-al-Rashid. Almamon, who reigned at BAGDAD in 814, imposed upon the Greek Emperor, Michael III., whom he had conquered, the condition that he should deliver to him the best books of Greece. The *Almagest* was among the number, and being translated into Arabic, was widely diffused; and the Emperor, not satisfied with encouraging others, was himself an observer. He measured an arc of a degree on the plain of Mesopotamia; brought together noted astronomers, and had them construct tables of the sun and moon more accurate than those of Ptolemy, and long known in the East as the "Verified Tables." The Arabs wrote several works on astronomy about this time, notably a Treatise on the Science of the Stars, containing the principal elements of the theory of the sun and the moon. But no changes were made in the *system* of Ptolemy by the Arabs; their work was confined to observations.

III.—THE COPERNICAN SYSTEM.

MODERN EUROPE is indebted to the Arabs for the first rays of light that penetrated the darkness in which it had been enveloped for twelve centuries. Alphonso, of Castile, it was who revived astronomy, and was the first to doubt the Ptolemaic theory. About this time Europe was indebted to the munificence of the Emperor Rudolph, of Germany, for a Latin translation of the *Almagest* made from the Arabic version. We now arrive at the celebrated epoch at which astronomy, emancipating itself from the narrow sphere which had hitherto confined it, advanced by rapid and continued progress to its pres-

ent exalted eminence. Now it was that Columbus discovered AMERICA, and a brilliant period of oceanic discovery followed. Soon after, Nicholas Copernicus, a Prussian, shocked, like Alphonso, at the extreme complication of the system of Ptolemy, tried to find a more simple explanation of the heavenly motions. He found ancient authority for assuming the sun as center of the planetary motions. And he finally worked out a complete system, which was published just before his death, entitled "De Revolutionibus Cœlestis." To avoid shocking received opinions and arousing prejudices he dedicated this immortal work to Pope Paul III. in the form of an hypothesis. As this system gained ground, religion was invoked to destroy it; but notwithstanding the inquisition, Galilei exerted a profound influence in establishing this new theory. To him we owe the application of the telescope to the observation of the heavenly bodies. He discovered with an instrument wrought by his own hand, the satellites of Jupiter, a miniature Copernican system, as well as the mountains on the moon, the spots on the sun, the phases of Venus, and the triform appearance of Saturn. He was the first also to overthrow the erroneous doctrine of Aristotle in regard to falling bodies. This great experimenter laid the foundations of modern science; his proofs consisted, not of the baseless logic that so characterized the philosophy of that day, nor in appeals to ancient authority, but in submitting his problems to tests at the hand of nature.

Meantime, Tycho Brahe, one of the most illustrious observers that ever lived, was making fine observations at Uranibourg, where the finest observatory yet seen by modern Europe had been built. He improved instruments, discovered the annual equation of the moon, made a catalogue of the fixed stars more accurate than that of Hipparchus, and lastly

made many exact observations on the planets, which were the basis of Kepler's researches in discovering the true system and laws of nature. Kepler adopted the Copernican system, and discovered three laws of planetary motion, whose importance can never be overestimated. These laws, besides describing precisely the planetary motions, led Newton to discover the universality of gravitation. But before we pass to Newton we must mention Huyghens, one of the most illustrious scientists of the century, who applied the pendulum to the clock, and thus perfected an instrument indispensable to accurate observations in astronomy. He also made various optical discoveries, and improved the telescope. About this time Römer, a Danish astronomer, calculated the velocity of light from observations on the eclipses of Jupiter's satellites. Flamsteed made very accurate observations, and improved the star catalogue; somewhat later, Bradley, while attempting to detect the parallax of the fixed stars, discovered the aberration of light, and the nutation of the earth's axis. But meantime Newton had reached the height of his glory. He proclaimed the universality of the law of gravitation, after putting it to test in the solar system. He left behind his great *Principia*, a work which gave physical science a mathematical basis, and entitles its author to everlasting renown. For he had brought order out of chaos; he was recognized as a great organizer of human thought, by virtue of that generalizing power which his *Principia* reveals. He began to develope the theory of tides, which was afterwards greatly elaborated by Laplace.

Contemporary with Newton lived Leibnitz, with whom Newton shared the honor of inventing the Infinitesimal Calculus, and Dr. Edmund Halley, who was the first in successfully predicting the return of a comet, in 1758. He was also one of the first to observe

a transit of Venus. But meantime Descartes had propounded a theory of vortex motion, which for a long time vied with the doctrine of universal gravitation, and was advocated after Descartes by the Bernoullis, several of the most illustrious men of the age. But at length the French mathematicians were convinced of the correctness of Newton's theory, and they began to apply mathematical analysis to universal mechanics, and by adopting analytical methods instead of the geometrical ones used by Newton, and by expressing the planetary forces thro' algebraic symbols, they were soon able to go far ahead of both Newton and his countrymen. There now gathered together in the French capital some of the brightest geniuses that ever adorned humanity. Among these were D'Alembert, Lagrange, LeLande, Laplace and Poisson. It is proper here also to mention the founding of learned societies, a great stimulus to scientific progress. Notable among these were the French Academy of Sciences, Paris; the Royal Society of London, and the Berlin Academy of Sciences. Problems were proposed and prizes offered for solutions. This led to very extended research in astronomy, which forever renders this epoch one of the most glorious in the history of intellectual developement. Nor should we here forget to mention the munificence of the French Kings. The Cassinis worked under the patronage of the French government, discovering four satellites of Saturn. The great works which closed the century were the "Mécanique Analytique" of Lagrange, and the "Mécanique Céleste" of Laplace.

In this immortal work Laplace not only tests the law of gravity in every part of the solar system, which Newton did not and could not do, and whose rigorous exactness now began to be questioned; but he proved, under certain conditions, the stability of the solar system. He says: "It seems that nature has arranged

this system for an eternal duration." His important discoveries are too numerous to be detailed; but it suffices to say, that he explained a great number of mysterious inequalities, which had hitherto baffled all mathematicians, in perfect accord with the law of Newton. He invented the "Spherical Harmonic Analysis," a Calculus indispensable in Celestial Mechanics. But the one thing due to Laplace that especially distinguishes this and the coming ages, is the use of the law of gravity as a means of discovery as real as observation: and it seems, therefore, not unjust to call this age the age of Laplace. We shall see this remark frequently illustrated in later discoveries.

To Lagrange, D'Alembert and Clairault in France, and Euler and Gauss in Germany, we owe vast improvements in mathematical analysis, and several discoveries in astronomy. This is indeed an epoch distinguished for revolutions no less in science than in human government. Sir William Herschel transformed the aspect of astronomy by his great telescopic discoveries. With instruments shaped by his own hand he sounded the depths of space, brought the double stars and nebulæ to vision, and made accurate catalogues of fixed stars, as did also LeLande at Paris. To Wm. Herschel we owe most of our knowledge regarding the structure of the stellar universe. But his best known discovery is that of the planet Uranus and its satellites. To him also are due some suggestions regarding the origin of the stars and planets; but the main credit of solving this problem is due to the Marquis De Laplace, who published to the world his theory known as the "Nebular Hypothesis," one of the boldest and grandest conceptions ever formed by the human mind. Sir Wm. Herschel was succeeded by his son, Sir John, who made extensive observations at the Cape of Good Hope.

A vast host of illustrious men now devoted them-

selves to astronomy, among whom may be mentioned Bessel, Arago, Airy, Dawes, Humboldt, Herschel and Struve. Early in the century four small planets were discovered between Mars and Jupiter. About 1820, Bouvard compiled tables of the planets according to the theory of Laplace; but the motion of the new planet Uranus could not be followed closely in calculation, even on taking into account all the known elements of the solar system. This anomaly finally led to the discovery of Neptune by Leverrier; a discovery eminently calculated to show the accuracy of modern astronomy; a discovery that will ever encircle the study of the skies with a halo of unspeakable glory. Great credit is also due to Mr. Adams, not only in the contest for the discovery of Neptune, but for his researches on the motion of the moon. To Delauney and Hansen our science is indebted for improved tables and several discoveries. Astronomy now receives liberal support from the United States; the naval observatory is organized on a firm foundation by Walker. Great improvements in navigation have been made at various times, notably in the time of Newton, and in America early in this century by N. Bowditch, the commentator on Laplace. About 1850 natural science began to be widely studied over the earth, and the doctrine of evolution, already foreshadowed by the "Nebular Hypothesis," began to assume definite form. But it was not until the Spectroscope was invented by Kirchoff and Bunsen that we could declare the process of world formation to be actually going on in the immensity of space. This revealed to us the nature of the heavenly bodies, and at once gave a solid basis to the doctrine of cosmic evolution. Solar Physics is now an important study; and great labor is at last making known to us the intimate constitution of the sun. The spots have been carefully studied, and a

connection detected between solar storms and magnetic disturbances on the earth.

Our sun is now regarded as a star of the milky way. The intimate relation of comets and meteors has also been ascertained, and nebulæ have been closely studied. An accurate chart of the moon has been made by Dr. Schmidt of Athens, who devoted to it 35 years of arduous labor. Argelander has catalogued 300,000 fixed stars in the northern hemisphere; and Dr. Gould is now at Cordoba, in the Argentine Republic, taking the star census of the southern heavens.

The parallaxes of a number of stars have been determined, tho' with extreme difficulty, and the proper motion of all has been espied. Huggins has applied to this motion Döppler's principle with reasonable success. That the whole solar system is sweeping thro' space has been incontestably established. A great number of small planets have been discovered, and the number, now 272, is yearly increasing. Hall, at Washington, with the great equatorial of the naval observatory, has discovered two satellites of Mars. A planet has been repeatedly searched for within the orbit of Mercury, suggested by the unexplained motion of the perhelion of that planet; but it has not been found. A slight disturbance in the motion of Neptune has led to a search for a transneptunian planet; but no discovery of one has yet been made. The state of astronomy at the present time is far more advanced than at any previous epoch in the history of the world. All the observatories are electrically connected. A discovery in one part of the world is in a few hours known all over the globe. The literature of the subject is very extensive and constantly growing. Great improvements in telescopes have been made of late years, especially by the Clarks in this country. Many powerful ones

daily survey the heavens. Among those recently built may be mentioned the great reflectors of Ross and Lassell, with which important discoveries have been made; and within the last few years have been built great refractors at the imperial observatories of Austria and Russia; and in this country one at the naval observatory at Washington; but we must not forget to mention the greatest and finest telescope of all, the Lick telescope, at the Lick observatory, Mt. Hamilton, California. One of the most interesting objects of study at the present time ~~is~~ are the Binary stars, which are now receiving considerable attention throughout the world.

The latest addition to the instrumentalities of astronomy is photography, the most delicate means yet employed for seeing difficult objects. It is now proposed to photograph the whole celestial sphere, and to prepare uniform charts of the heavens, whose value to future astronomers can hardly be estimated. This would be by far the highest achievement in the history of any science, insuring to future astronomers a rich harvest, and to sidereal astronomy, the astronomy of the future, a permanent foundation.

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